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SKYLAB PROGRAM PAYLOAD INTEGRATION
Skylab Film Environmental Effects

Skylab Program Office

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

The effects of the Skylab environments on the 22 types of film used for data recording on Skylab were evaluated. Environmental histories and sensitometric curves for 114 rolls of film used for this evaluation are presented. Photographic parameters evaluated in detail were film fogging of black and white films, changes in maximum density of color film, latent image fading and changes in film sensitivity. Other photographic and film physical anomalies such as electrostatic exposure, emulsion cracking and reciprocity failure were also documented. Results based upon comparison of film sensitometric data for flight film with ground control film and ground test film are presented independently for each film type.

The study showed that photographic film, almost without exception, fulfilled the requirements of the Skylab applications in which it was used. Environmental film degradation, although present on almost every roll, did not preclude recording sufficient data to meet experiment requirements for all film, except film type SC-5. Specific conclusions are provided in the areas of further analyses, tests and developments that will enhance data recording with photographic film in future space missions.

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NONSTANDARD ABBREVIATIONS

AM	Airlock Module
AS&E	American Science and Engineering, Inc.
ATM	Apollo Telescope Mount
CSM	Command and Service Module
EREP	Earth Resources Experiment Package
GCR	Galactic Cosmic Radiation
GMT	Greenwich Mean Time
H & D	Hurter & Driffield
IU	Instrument Unit
JSC	Lyndon B. Johnson Space Center
MDA	Multiple Docking Adapter
NASA	National Aeronautics and Space Administration
NRL	Naval Research Laboratory
OWS	Orbital Workshop
PD	Passive Dosimeters
PRD	Personnel Radiation Dosimeters
PTD	Photographic Technology Division
RH	Relative Humidity
RSM	Radiation Survey Meter
SAL	Scientific Airlock
SL1	Skylab 1
SL2	Skylab 2

NON STANDARD ABBREVIATIONS (Concluded)

SL3	Skylab 3
SL4	Skylab 4
TLD	Thermolumenescent Dosimeter
UT	University of Texas at Austin
VABD	Van Allen Belt Dosimeter

1. INTRODUCTION

The use of photographic film on the Skylab Program was the most dramatic example of the feasibility of photographic data recording in space in the history of the space program. More than 400 rolls of photographic film were used on Skylab to support more than 30 scientific experiments and crew operational photography. This totaled nearly 23 kilometers of film. Because of the importance of the data to be recorded photographically during Skylab orbital operations, National Aeronautics and Space Administration (NASA) scientists were concerned about potential film degradation resulting from storage and use of film in the Skylab environment during the comparatively long missions. Therefore, NASA sponsored test programs to define environmental constraints and protective measures to ensure that any photographic degradation would be held within acceptable limits. These programs investigated the effects of storing film in various combinations of temperature, relative humidity, and ionizing radiation environments. Based on the results of these tests, storage vaults to protect the photographic film were fabricated and incorporated in Skylab.

1.1 Purpose

The purpose of this study is to provide a single report that describes the effects of Skylab environments on the film and provides performance data for all Skylab flight film for which information was available. The report is also a source document for future space systems and experiments that use photographic film. It will aid the evaluation of the use of photographic film for space applications, selection of film, establishment of criteria for environmental protection, design of spacecraft film repositories, and definition of pre-mission test requirements for systems that employ photographic film.

1.2 Scope

All available environmental mission performance and test data pertinent to the environmental effects on Skylab film were compiled and analyzed. Based on the analyses, representative rolls of each type of film and each applicable Skylab mission were selected for additional analysis and discussion. Because of differences in the film types used on Skylab, each type of film is reported independently. Analyses of each type included correlation of Skylab-flight film data to ground-control film data. Based on these analyses, the separate effects of temperature, relative humidity, and ionizing radiation were investigated and quantified where possible. Observed environmental effects on flight film were correlated with values predicted from pre-mission environmental testing. Interviews with principal investigators

for Skylab experiments that used film were conducted to obtain their evaluation of adequacy of the film to meet their experiment objectives; film-related problems, shortcomings, degradation, or anomalies; and recommended improvements for future use of photographic film in space. Significant results of these interviews are incorporated in the "Performance Evaluation" paragraph for each type of film.

Recommendations for future programs are included in the "Recommendations" section of the report.

1.3 Summary

This Skylab Film Environmental Effects Study encompassed collection of data sufficient to define and analyze the Skylab environments and environmental effects on 24 types of photographic film planned for use or used on the Skylab. This report provides a description of each film type, the method by which it was processed and the application in which it was used during the Skylab mission.

Skylab environments are described in terms of the general atmospheric environments within each major Skylab module and film vault where film was stored and as detailed radiation, temperature and relative humidity timelines for each roll of film analyzed during this study. Environmental timelines provide the environment history of each roll from the time sensitometric film calibration exposures were placed on flight film until after the Skylab mission when the film was processed. The total ionizing radiation dose for each roll analyzed was computed using the Vette AP7 Model of the Earth trapped radiation environment and a computerized shielding model of the Skylab.

Evaluation of the effects of the Skylab environment was completed for the 22 types of film actually used for data recording on the orbiting Skylab. Photographic parameters evaluated in detail were film fogging of black and white films, changes in maximum density of color film, latent image fading and changes in film sensitivity. Other photographic and film physical anomalies such as electrostatic exposure, emulsion cracking, reciprocity failure, etc., were documented. Results of the evaluation are presented independently for each film type. Analyses were based, primarily, on film sensitometric curves obtained from available flight film, ground control film and ground test film data.

This study showed that photographic film, almost without exception, fulfilled the requirements of the Skylab applications in which it was used. Environmental film degradation, although present on almost every roll, did not preclude recording sufficient data to meet experiment requirements for all film, except film type SC-5. Specific conclusions are provided in the areas of Skylab environments, environmental effects on photographic film and film related problems.

Skylab Principal Investigators were interviewed regarding film performance on their experiments. Results identified during these interviews are incorporated into this report. These investigators also provided recommendations based on their work with Skylab films relevant to obtaining improved photographic data on future space programs. These recommendations are also included in this report.

2. SKYLAB FILM

The study investigated 24 different types of photographic film prepared for launch on Skylab. Because of the absence of sensitometric data, the nuclear emulsion pack used for the S009 Nuclear Emulsion Experiment and polaroid film used in the SX-70 camera were not included. Films investigated were manufactured by Eastman Kodak Co., Rochester, N.Y., except SC-5, which was manufactured by Kodak Pathe' of France. The Kodak name and film type number are given below.

TYPE/NUMBER	KODAK NAME
NTB3	KODAK Special Film, Type 088-03
104-06	KODAK Special Film, Type 104-06
SC-5	SC-5 Film
101-05	KODAK Special Film, Type 101-05
101-06	KODAK Special Film, Type 101-06
103a-0	Spectroscopic Film
SO-101	Solar Flare Patrol Film (ESTAR-AH Thin Base)
3414	High Definition Aerial Film (ESTAR Thin Base)
3400	PANATOMIC-X Aerial Film (ESTAR Thin Base)
SO-212	Spectrographic XUV Film (ESTAR Thin Base)
SO-022	PANATOMIC-X Aerial Film (ESTAR Base)
026-02	KODAK Special Film, Type 026-02
3401	PLUS-X Aerial Film (ESTAR Thin Base)
2403	TRI-X AEROGRAPHIC Film (ESTAR Base)
SO-265	TRI-X Recording Film (ESTAR Base)
2485	High Speed Recording Film (ESTAR-AH Base)
2424	Infrared AEROGRAPHIC Film (ESTAR BASE)
SO-242	Aerial Color Film (ESTAR Thin Base)
SO-356	High Definition EKTACHROME (ESTAR Base)
SO-268	EKTACHROME MS (ESTAR Thin Base)
SO-168	EKTACHROME EF (ESTAR Thin Base)
2443	AEROCHROME Infrared (ESTAR Base)
3443	AEROCHROME Infrared (ESTAR Thin Base)
SO-131	High Definition AEROCHROME Infrared (ESTAR Thin Base)

A general description of each type of film is given in Appendix A. All film types were evaluated, except PANATOMIC-X Aerial Type 3400 and TRI-X AEROGRAPHIC Type 2403. These films were intended for use on the Coronograph Contamination Measurements Experiment, T025, which was to have been operated in the solar Scientific Airlock. However, the airlock was used for the parasol that was deployed to shade the Orbital Workshop after the micrometeoroid shield was torn away during launch. Although T025 was finally operated during crew extravehicular activity on the last mission, another film (TRI-X Recording Film Type SO-265)

was substituted. Therefore, Type 3400 was never used to record in-flight data, and Type 2403 was never launched. Consequently, neither of these films was processed.

The many areas of application represented by the Skylab experiments account for the variety of film types flown. These experiments recorded scientific data over a spectral range from the soft X-ray region beginning at 0.2 nm (2 angstroms) through the near infrared region up to 900 nm (9000 angstroms). In addition, 20 kV electrons were recorded photographically in a special electrographic camera. Appendix B includes a list of the scientific experiments for which each type of film was used. The appendix identifies the film type, principal investigator or experiment scientist, spectral region of application, and objective of each experiment. Although principal investigator's comments are incorporated in Section 4 of this report, additional information and results that postdate this study may be available through personal contact with each principal investigator or science advisor. Therefore, the professional address of each principal investigator or science advisor is given in Appendix C.

2.1 Film Processing

Processing of Skylab film was carefully controlled to maximize the scientific output and quality of each roll and, in some cases, each frame of film data. Processing procedures were established before the Skylab mission based on the nature of the data to be recorded and analytical requirements of each experiment. The procedures were adjusted to achieve the desired film response curve on each roll of film. Therefore, before processing the flight film, each processing machine was certified to assure the desired film response. This was achieved by making small changes in processing time, temperature, or chemistry. Table 2-1 lists the basic film processing data for each Skylab film. Variations in machine speed from mission to mission are due to adjustments required by the certification procedure.

The processing locations in Table 2-1 show that much of the film was processed by the Photographic Technology Division (PTD) at the Lyndon B. Johnson Space Center (JSC), Houston, Texas. Other agencies and companies that processed Skylab flight film were:

Naval Research Laboratory (NRL), Washington, D.C.;
University of Texas at Austin (UT), Austin, Texas;
Aerospace Corporation, Los Angeles, California;
American Science and Engineering (AS&E), Cambridge, Mass.

Processing information was obtained by personal contact with these organizations and from reference documents 1.a through 1.d. Additional film handling and detailed processing information is given in references 2.a through 2.i.

TABLE 2-1 SKYLAB FILM PROCESSING DATA

FILM	EXPERIMENT	PROCESSING LOCATION	PROCESSOR	CHEMISTRY	MACHINE SPEED/ DEVELOPMENT TIME	DEVELOPER TEMPERATURE
NTB3	S201	JSC/PTD	Hi-Speed		3.5 fpm	85°F
104-06	SO82A, SO82B	NRL	Hand	D-19 1:1	4 min	68°F
SC-5	S183	JSC/PTD*	Hand	D-19B 1:1	4 min	68°F
101-05	S183	JSC/PTD*	Hand	D-19 1:1	4 min	68°F
101-06	S019, S020	UT, NRL	Hand	D-19 1:1	4 min	68°F
103a-0	S183	JSC/PTD	Hi-Speed	D-19B	29 fpm	75°F
SO-101	Hα	Aerospace	Fultron	D-19 1:2	2 min	70°F
3414	S190B	JSC/PTD	Fultron #1	MX-819	22 fpm	90°F
SO-212	S054	AS&E	Filmline**	D-96	7.5 min	68°F
SO-212	S056	JSC/PTD	Hi-Speed	D-76	8 min 50 sec	76°F
SO-022	S190A	JSC/PTD	Fultron #2	MX-819	8.5 to 12 fpm	75°F & 82°F
026-02	S052	Aerospace	Fultron	AD-112	8 min	70°F
3401	S191	JSC/PTD	Houston	D-19	46 fpm	85°F
3401	S233	JSC/PTD	Hi-Speed	D-76	5.5 fpm	75°F
SO-265	T025, S063	JSC/PTD	Hi-Speed	D-76	4 fpm	75°F
2485	T027, S063, S232, S073	JSC/PTD	Hi-Speed	D-19	4, 5 & 30 fpm	85°F
2424	S190A	JSC/PTD	Hi-Speed	D-19	SL2-4 fpm; SL3,4-5 fpm	70°F
SO-242	S056	JSC/PTD	VMT 1811 #3	EA-5	6 fpm	110°F
SO-242	S190B	JSC/PTD	VMT 1811	EA-5	7 fpm	110°F
SO-356	S190A	JSC/PTD	Houston	ME-4	12.5 fpm	98°F
SO-368	Op, T053, S063, S191	JSC/PTD	Hi-Speed	ME-2A	4 fpm	75°F
SO-168	Op, M479	JSC/PTD	RAM	ME-4	70 fpm	85°F
SO-168	Op, M151, M509, S191	JSC/PTD	RAM	ME-4	85 fpm	98°F
2443	S190A	JSC/PTD	VMT 1811 #3	EA-5	SL2-5 fpm	104.5°F
2443	S190A	JSC/PTD	VMT 1811 #3	EA-5	SL3-8 fpm; SL4-7 fpm	110°F
3443	S190B, M479	JSC/PTD	VMT 1811 #3	EA-5	9 fpm	120°F
SO-131	S190A	JSC/PTD	VMT 1811 #3	EA-5	4 fpm	93°F

*Processed by Andre Vuillemin, Laboratoire d'Astronomie Spatiale, Marseille, France

**Modified by American Science and Engineering (AS&E)

3. THE SKYLAB ENVIRONMENT

The films used in Skylab were launched in either the unmanned Skylab 1, or in one of the Command Modules on Skylab 2, 3, or 4. Films were returned in one of the Command Modules after remaining in orbit for one, two, or all three of the manned missions. The film was stored in the Skylab environments for periods as long as 272 days. This section presents the environmental history of Skylab as it applies to the film used.

The Skylab mission profile is shown in Figure 3-1. The frequency and duration of the missions, based primarily on medical considerations, were planned to be 28, 56, and 56 days, with unmanned periods of 1, 60, and 30 days between launches. This resulted in a total planned mission duration of 231 days. However, actual mission duration was 272 days, including manned periods of 28, 59, and 84 days preceded by unmanned periods of 11, 36, and 52 days, respectively. The first unmanned period was extended to provide time for analysis, planning, fabrication, stowage, and training for repairs made necessary by a launch phase anomaly.

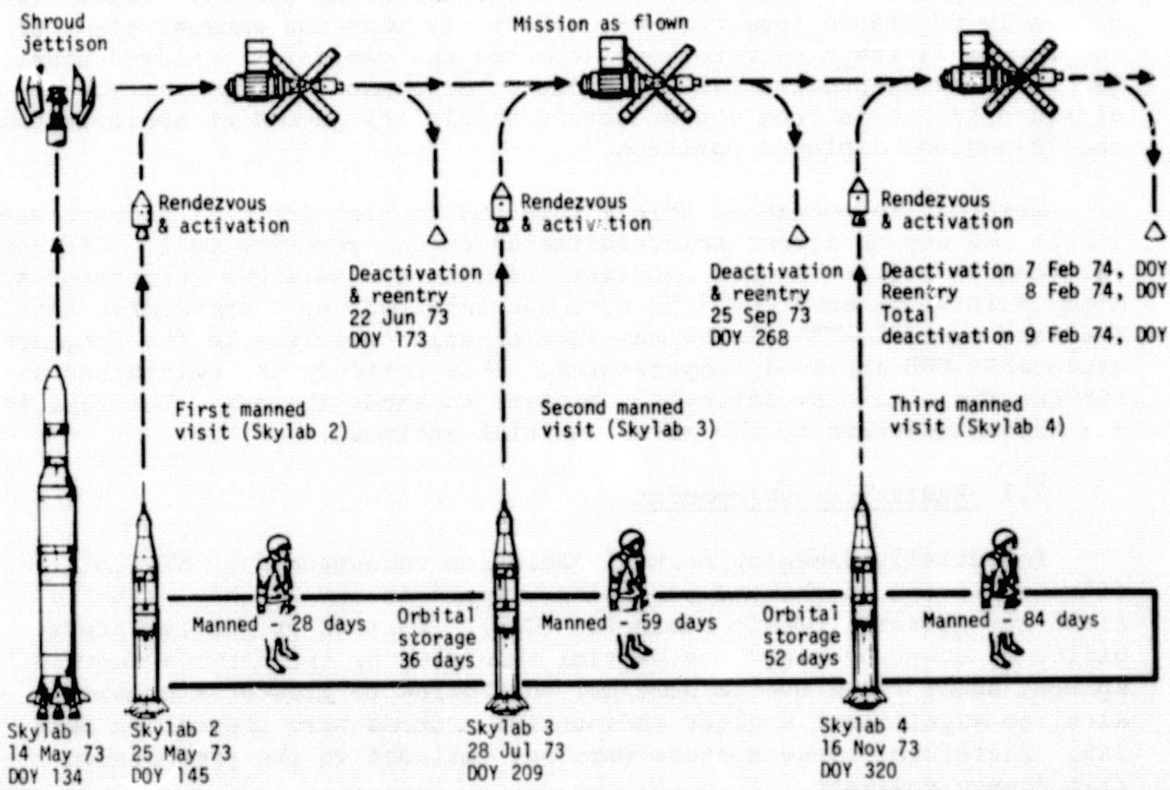


FIGURE 3-1 SKYLAB MISSION PROFILE

The second unmanned period was shortened to return a crew as quickly as possible to attend to spacecraft repairs. The third unmanned period was extended to provide prime opportunities for viewing the newly discovered Comet Kohoutek. The second and third manned periods were extended to obtain additional experimental data.

The Skylab mission began at 17:30 Greenwich Mean Time (GMT) on May 14, 1973, with the launch of Skylab 1 (SL1) and ended on February 8, 1974, with the undocking of the Skylab 4 (SL4) Command and Service Module (CSM). The unmanned Skylab was launched from Launch Complex 39 Pad A at the NASA Kennedy Space Center, Cape Kennedy, Florida. The launch configuration consisted of a Saturn-IC first stage, Saturn II second stage, and the Skylab payload. Skylab elements were an Apollo Telescope Mount (ATM), Multiple Docking Adapter (MDA), Airlock Module (AM), Instrument Unit (IU), and Orbital Workshop (OWS). The unmanned Skylab was placed in a nominal 235-nautical-mile (435-kilometer) near-circular orbit, inclined 50 degrees to the Equator.

At approximately 63 seconds in the Skylab 1 boost phase, an anomaly occurred that resulted in the loss of the meteoroid shield around the OWS. The shield was designed to protect the OWS against micrometeoroid penetration and served as a thermal insulator. Loss of the shield resulted in partial deployment of the OWS solar array panels. Panel 2 subsequently separated from the OWS, apparently when the exhaust plume of the Saturn II stage retrorockets impacted the partially deployed panel. OWS solar array panel 1 failed to deploy on command because it was restrained by debris from the meteoroid shield and jammed at approximately the 10-percent deployed position.

Loss of the meteoroid shield resulted in high internal temperatures in the OWS due to direct solar radiation on the workshop wall. Off-normal vehicle attitudes were necessary to maintain safe OWS temperatures. After initial maneuvering, the attitude selected was a compromise that provided partial ATM solar-array line-of-sight pointing to the Sun, and acceptable OWS internal temperatures. This attitude was maintained until the Skylab 2 crew deployed a parasol to shade the OWS. The vehicle was then maneuvered to the solar inertial attitude.

3.1 Radiation Environment

Potentially damaging natural radiation encountered by Skylab films consisted of charged particles trapped in the Earth's magnetic field and galactic cosmic radiation (GCR). Because of the low probability of occurrence and the partial shielding by the Earth's magnetosphere, solar flare events were not considered to present a problem. Also, no significant nuclear radioactive sources were present on Skylab. Therefore, these sources were not included in the pre-mission film damage analyses.

The primary particles of concern were those trapped by the Earth's magnetic field in the regions known as the Van Allen belts. These belts consist primarily of free protons and electrons trapped in the magnetic field of the Earth. However, the distribution of the charged particles throughout the field is not uniform. Because of several factors--including charge, mass, particle velocity, and the Earth's magnetic field strength--only a portion of the magnetic field can trap and retain the charged particles. The intensity of the magnetic field at a given point controls particle density at that point. Because the intensity of the Earth's magnetic field is not completely uniform, it follows that the spatial distribution of charged particles in the Van Allen belts is not uniform. Spatial distribution of the particles in the belts is further complicated by (1) the center of the Earth's magnetic field is not at the geometrical center of the Earth, and (2) the axis of the magnetic field is not parallel with the spin axis of the Earth. Together, these factors cause a distortion of the Van Allen belts when viewed in geocentric coordinates. This distortion is called the South Atlantic Anomaly.

Figure 3-2 illustrates the proton radiation intensities in the anomaly based on the Vette API proton model (Ref. 3a) at Skylab altitude.

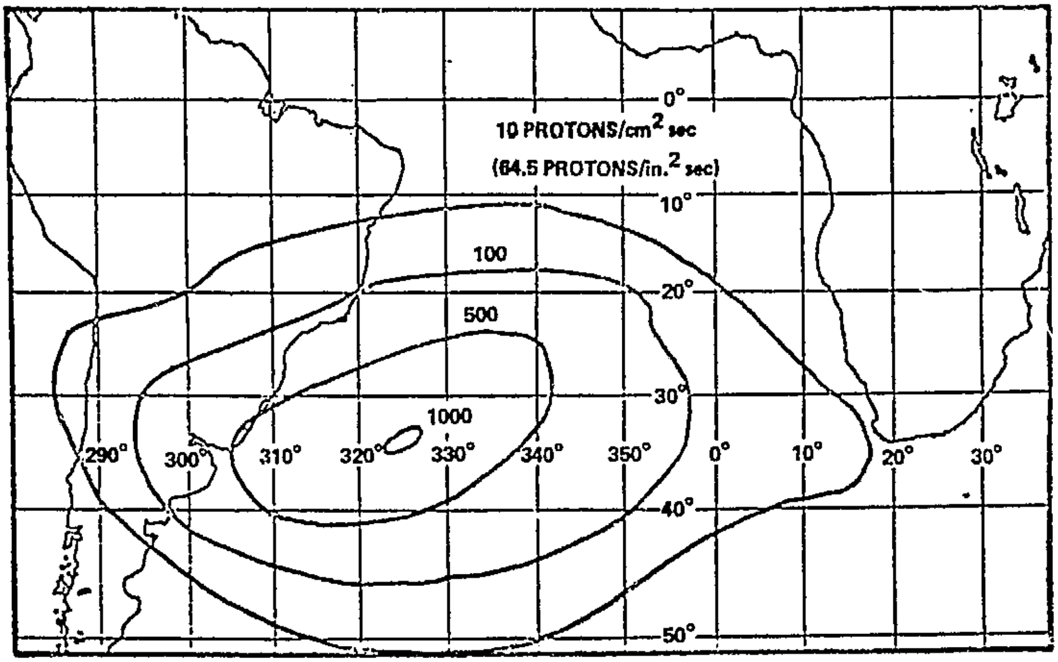


FIGURE 3-2 CONSTANT FLUX CONTOURS OF THE SOUTH ATLANTIC ANOMALY

Trapped proton dose rates and shielding were calculated using the Vette AP7 proton model (Ref. 3b) and the Skylab orbit. The dose due to protons was not continuous but was received in 8 or 9 pulses per day as the orbit penetrated the South Atlantic magnetic anomaly. Figure 3-3 shows the radiation dose calculated for each pass that penetrated the anomaly during the first 120 hours of the mission. This pattern was repeated every 71 revolutions (approximately 5 days).

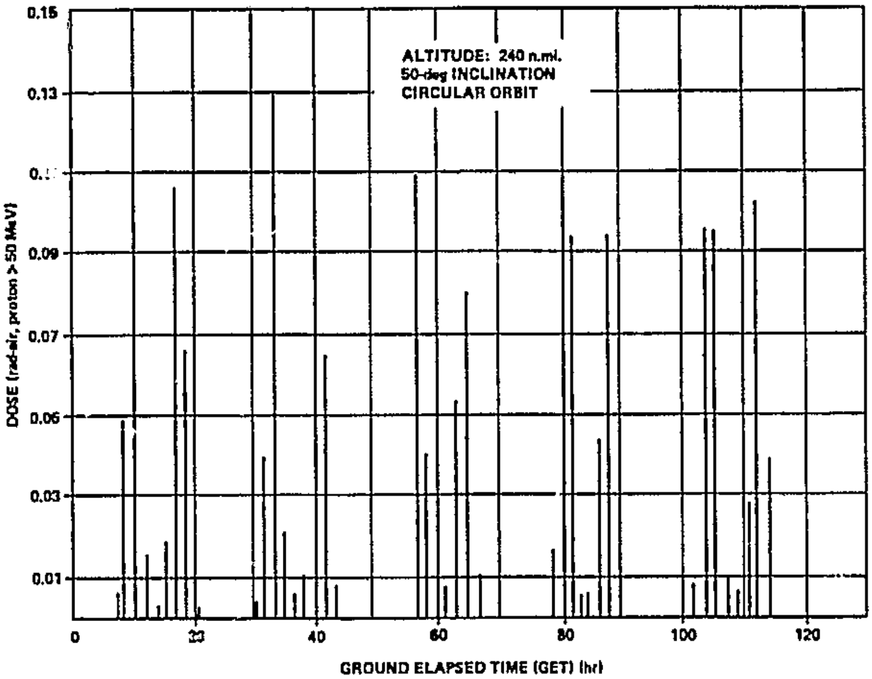


FIGURE 3-3 FREE-SPACE PROTON DOSE AS A FUNCTION OF TIME FOR PASSES THROUGH THE SOUTH ATLANTIC ANOMALY

The smallest pulses lasted about 5 minutes and contained few high-energy protons. The longest pulses lasted about 16 minutes with 90% of the high-energy protons received during an 8-minute interval. Approximately 12 hours per day were free of trapped proton doses. The proton flux measured during the Skylab mission was only about 80% of the flux predicted by the AP7 model for protons above 50 MeV. This was well within the factor of two uncertainty usually quoted. On-board measurements indicated that a harder proton spectrum should be incorporated in the model to a lower altitude when the Vette models are updated.

Film degradation caused by Bremsstrahlung radiation created by electrons stopped in the outer material of Skylab was a concern. The Vette electron environment model, AE2 projected to 1968 (Ref. 3b), was used to obtain premission trapped electron dose rates and for shielding calculations. The dose due to the electron belts was received during approximately 18 pulses per day. These pulses lasted from a few minutes

to about a half hour. About one-third of the electron flux above 0.5 MeV was due to inner belt electrons, while the remainder was due to Skylab's encounter with the "outer" belt "horns." The so-called "horns" were encountered only at the extreme north and south latitudes. The electrons present no problem to film stored in the film vaults. The main concerns about electron damage were during EVA activities, when the film was installed in the ATM, and when film was used in cameras on a boom extended through the Scientific Airlock.

Galactic Cosmic Rays (GCR) are a low flux of charged particles consisting of protons, alpha particles, and other stripped nuclei with atomic numbers up to approximately 28. The approximate composition of GCRs is 87% protons, 12% alphas and the remainder heavier nuclei. The GCR energy spectrum extends to very high energies (up to 10^{15} MeV), but the number of these high-energy particles is very small compared to the number of lower-energy particles. Because of the higher energies involved, shielding and dose-rate calculations for GCR were somewhat different from those for Van Allen Belt protons. These GCR particles are very penetrating, and the introduction of moderate amounts of shielding increases the dose due to secondary radiation production. Consequently, shielding calculations for specific spacecraft like Skylab were not made, but instead, reference was made to existing complex transport and secondary production calculations performed for simplified spherical shields. A GCR dose of 0.010 rad/day was used for the Skylab mission (Ref. 3c, 3d, 3e). This dose rate was applied equally to all points within Skylab.

Although film dose rates were lower than predicted, rates measured during the Skylab mission indicated that the radiation environment assumed before the mission was adequate to predict radiation damage to film and determine shielding thicknesses. Dose, or the amount of radiation received by a substance, is defined as the amount of radiation absorbed by that substance. The unit of radiation absorption used for Skylab was the rad. One rad is the absorption of 100 ergs of ionizing radiation per gram of material. Common rad units are rads-air or rads-tissue. Because tissue has a higher energy absorption coefficient than air, the rad-tissue is about 10% higher than the rad-air dose; that is, about 10% less radiation is required to produce the rad-tissue dose. The rad-air unit is used in this report to define radiation dose.

The Flight Data Calculated Dose was calculated using the Vette environmental models, which established the spectral radiation outside Skylab in its planned orbit. This information was fed into another computer program that determined radiation dose at points inside Skylab. Shielding afforded by Skylab was represented by a complex geometrical analog consisting of more than 4000 shield volume elements composed of about a dozen different materials.

Dose calculations during mission flights were made by the Space Radiation Analysis Support Group at JSC, using information supplied by the Experiment Procedures Group and dose rates determined for various locations throughout Skylab. The latter group supplied the times each roll of film was in use. The exact time a film was out of the film vault was essential to dose determinations. If the film were outside the vault during a high-dose pass through the South Atlantic anomaly, the film received a higher dose than it would have received during a pass that did not penetrate the anomaly. Daily average doses were used for film while it was stored in the vault and Daily Film Dose Logs and cumulative Film Dose Logs were prepared for all rolls of film stored in the OWS vault (Ref. 3f).

Doses for film stored in MDA vaults and used in the ATM were calculated only for the SL1/2 mission. Martin Marietta estimated the dose to MDA films examined in this report for SL3 and SL4 using data prepared by the JSC Space Radiation Analysis Support Group.

Radiation dose timelines given in Appendix D were obtained by subtracting the day-to-day values given in the cumulative dose logs.

The preflight dose rates given in this report were obtained from references 3g, 3h, 3l. Operational radiation measuring instruments carried on Skylab that provided comparisons with the dose calculations were; 1) Van Allen belt dosimeter (VABD) near the center of the OWS crew quarters, 2) radiation survey meter (RSM) used throughout the cluster, 3) personnel radiation dosimeters (PRD) (cigarette-pack size) carried by crew members or stored in specific locations in the OWS, 4) passive dosimeters (PD) containing lithium fluoride thermolumenescent dosimeter (TLD) chips, nuclear emulsions, high-atomic-weight particle detectors, and neutron activation foils, and 5) the Electron Proton Spectrometer.

Additional comparisons were obtained from results of the D008 (Radiation in Spacecraft) experiment, which measured the radiation in the Command Module with one active and five passive dosimeters. The active dosimeter gave instantaneous readouts that were telemetered to Earth. Passive dosimeters had to be returned to Earth before data could be obtained. The passive dosimeters were secured at five locations corresponding to different shielding thicknesses in the SL2 Command Module.

In general, preflight calculated doses and measured doses agreed quite well and tended to confirm the validity of the assumed environment and spacecraft mockup. Table 3-1 gives the ratios of measured to calculated doses at various locations in the OWS for doses measured by different instruments (Ref. 3j, 3k).

TABLE 3-1 RATIO OF MEASURED TO CALCULATED DOSES AT VARIOUS OWS LOCATIONS

Location	Instrument			
	VABD	RSM	PRD	PD
Central Crew Quarters	0.73	0.73		
Sleep Compartment			0.74	
Experiment Compartment		0.52	0.50	
Antisolar Scientific Airlock		0.65	0.48	
Drawer A OWS Film Vault			0.76	
SL2 Return				
Drawer B OWS Film Vault				2.04
Drawer F OWS Film Vault				2.45
SL3 Return				
Drawer B OWS Film Vault				1.81
Drawer F OWS Film Vault				2.01

The table shows ratios of less than one for all points except Drawers B and F of the OWS Film Vault. The five passive dosimeters for the D008 experiment also show ratios less than one. The ratios for Drawers B and F are not out of line for shielding calculations but are completely inconsistent with the results for other locations. Investigations during the Skylab flight and after the mission revealed no apparent reason for the discrepancy, the cause of which is still not known (Ref 31).

The doses measured by the Van Allen Belt dosimeter were in generally good agreement with calculated doses. They also confirmed the validity of the methods used for preflight calculations. This dosimeter had two readouts, one simulated skin doses and the other a depth, or tissue dose. The skin dose, which should have been sensitive to small inaccuracies in the shielding model, was generally overestimated. This overestimation indicates that fewer low-energy protons should be used in the environmental model. The tissue (or depth) doses were generally in closer agreement with calculations but had a tendency to be underestimated. The lower calculated doses indicate that the assumed spectra above 50 MeV are greater than was assumed in the AP7 proton model. However, the net effect produced only minor changes in calculated doses. Van Allen Belt dosimeter doses calculated using the spectrum determined with the electron proton spectrometer data showed excellent agreement with measured values, thus giving additional credence to the shielding model and dose calculation methods.

3.1.1 Skylab Film Vaults

Environmental protection provided for the film consisted of film vaults for radiation shielding and ambient temperature and humidity

control to keep the crew comfortable. Film vaults were provided in the OWS for the Earth Resources Experiment Package (EREP), corollary experiment and operational film, and in the MDA for the ATM film. The vaults were aluminum with wall thicknesses based on pre-mission tests that defined the shielding required to protect the film in the particular vault or compartment.

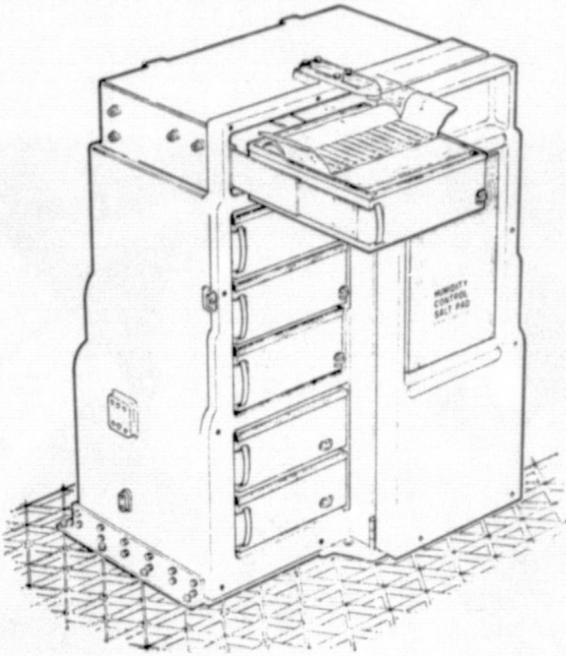
3.1.1.1 OWS Film Vault - The OWS film vault employed one large aluminum casting with 12 drawers: 2 with 0.25 in. (0.635 cm) of shielding, 5 with 1.9 in. (4.82 cm), 1 with 2.9 in. (7.37 cm), and 4 with 3.4 in. (8.64 cm), as shown in Figure 3-4 (Ref. 3a). It occupied a total envelope approximately 54 in. (137 cm) high, 40 in. (101.8 cm) wide, and 26 in. (66 cm) deep. Its weight, without film, was approximately 2250 lb.

The front of the vault was closed by two doors, hinged in the center of the vault face. During launch, the doors were secured to the main body of the vault by bolts. This eliminated the need for massive hinges that would not be required in the zero-g environment of space. While on orbit, the vault doors were held closed by suitcase-type latches.

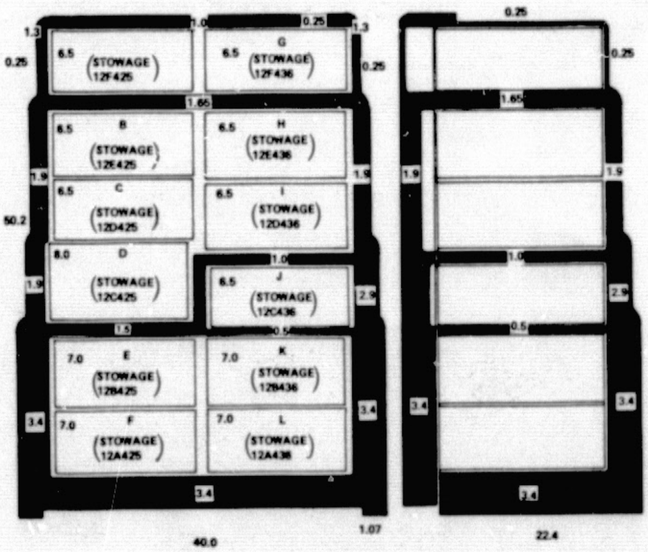
The insides of the doors had indentations to provide the proper amount of shielding and room for mounting potassium thiocyanate salt pads. The pads absorbed or released moisture to the surrounding atmosphere, depending on the relative humidity. The number of salt pads in the vault was selected to maintain a relative humidity of 45% $\pm$15% during storage periods considering the controlled leakage of the doors.

3.1.1.2 MDA Film Vaults - Four film vaults were installed in the MDA to provide stowage for the ATM cameras and film (Ref. 3m). The vaults were of various sizes and wall thicknesses to meet the physical and radiation requirements given in Table 3-2.

The vaults were mounted in the MDA at locations best suited for crew operation and to sustain launch loads. The vaults were fabricated from 6061-T6 aluminum. Doors were attached to each basic box with a continuous piano hinge and locked in place for launch loads with expando pins. During activation by the SL-2 crew, the expando pins were replaced with pip pins. The doors were equipped with a friction device to control inertia forces on the door during crew operations in zero g. The MDA vaults are shown in Figure 3-5.



a. Isometric view



NOTE: ALL DIMENSIONS ARE IN INCHES.

b. Wall thickness

FIGURE 3-4 OWS FILM VAULT

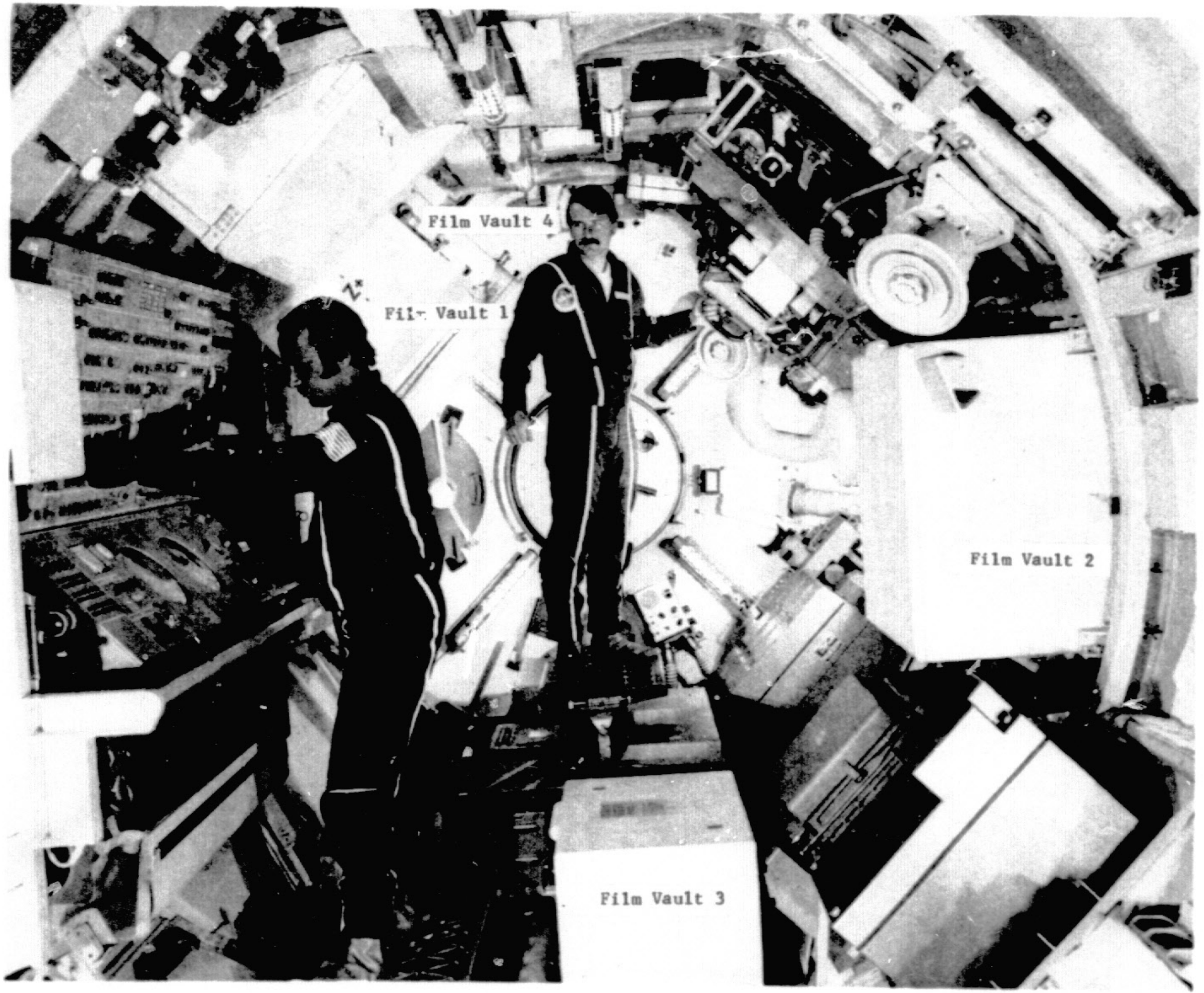


FIGURE 3-5 MDA FILM VAULTS

TABLE 3-2 MDA FILM VAULT DATA

FILM VAULT	ATM EQUIPMENT	SIZE (INCHES)	VAULT WEIGHT (POUNDS)	WALL THICKNESS (INCHES)
No. 1	(2) S082A Cameras/ Canisters (2) S082B Cameras/ Canisters	23x24x40	260	0.50
No. 2	(2) S052 Cameras (2) S054 Magazines (2) S056 Magazines/ Shoe	32x23x29	452	1.00
No. 3	(1) S052 Camera (1) S054 Magazine (1) S056 Magazine/ Shoe	21x24x30	495	1.50
No. 4	(3) H Alpha 1 Magazines	34x28x26	302	0.09 Min

3.2 Skylab Thermal and Atmospheric Environments

Temperature control in Skylab was largely passive. The vehicle was heated by solar and Earth radiation and heat from equipment operation and crew metabolism. Active systems provided additional control and proper heat distribution. The temperature and relative humidity histories in the OWS and MDA, and their respective film vaults, are presented and briefly described in this section. These histories, plus the environments to which film was subjected during orbital use and pre- and post-mission handling, compose the environmental history for each film roll presented in Appendix D. Source of environmental data are listed in references 4a through 4p.

3.2.1 OWS Temperature History

The OWS average internal temperature history is presented in Figure 3-6. The average of the readouts from thermal sensors on the ceiling grid of the experiment-level compartments was used to determine this temperature.

The ground thermal conditioning system controlled the OWS average internal temperature to approximately 55°F at liftoff. At liftoff plus 63 seconds, the meteoroid shield tore loose from the OWS, exposing the gold-coated Kapton on the cylindrical tank wall to the orbital environment. As a result, the OWS external tank wall temperature began to climb at an abnormally high rate at orbital sunrise, 67 minutes after liftoff.

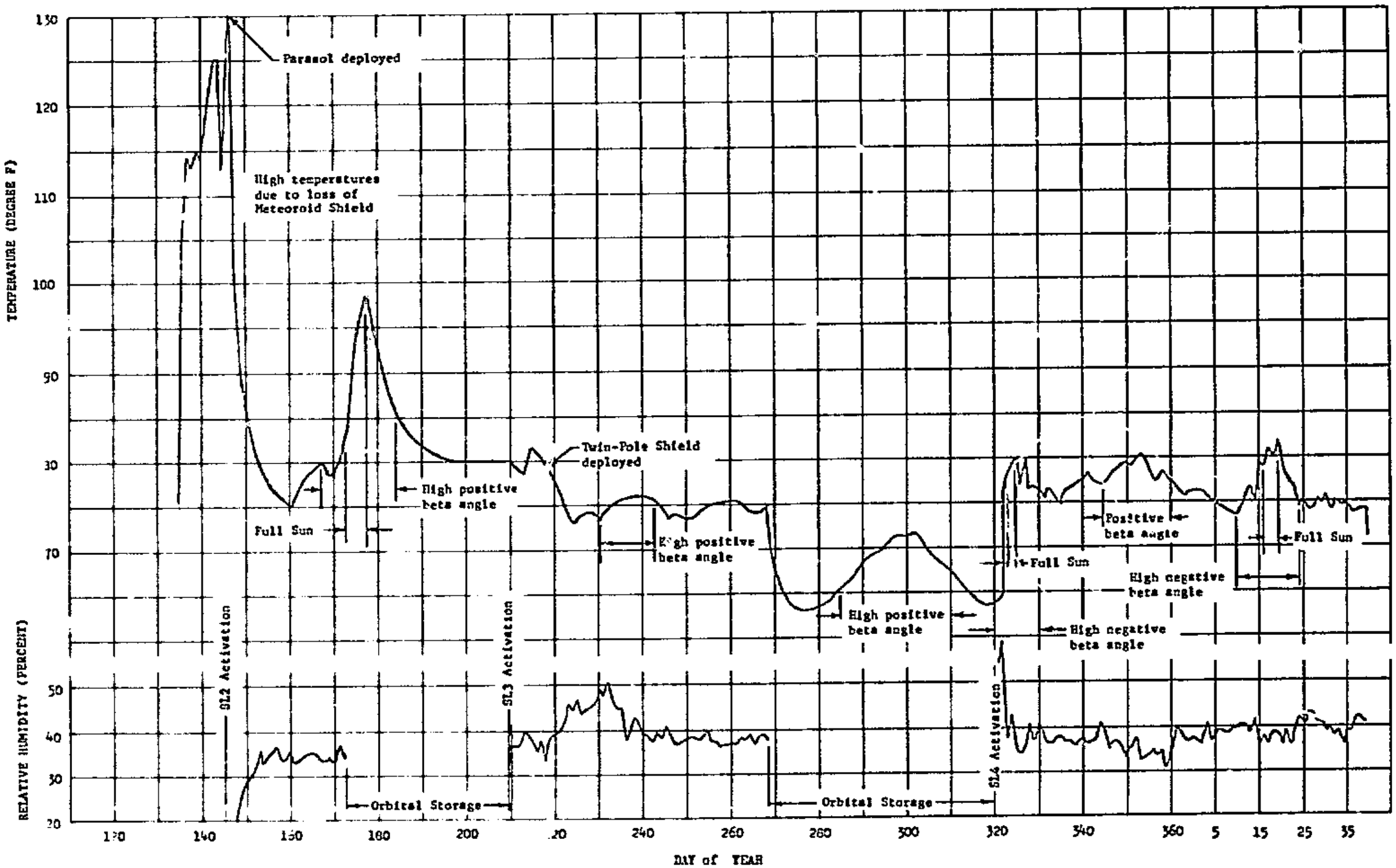


FIGURE 3-6 OWS AVERAGE TEMPERATURE AND RELATIVE HUMIDITY

OWS internal temperatures also began to rise as the heat soaked through the polyurethane insulation on the inside tank wall. Analytical predictions indicated that the OWS internal temperature would approach 160°F if the vehicle maintained the planned solar inertial attitude. To minimize degradation of food, film, tapes, and other equipment, the vehicle was commanded into various attitudes so that solar-radiation impingement on the gold foil would be reduced. Other considerations, such as electrical power availability, control gas use, and extreme temperatures of equipment in other areas of Skylab, were taken into account in determining the optimum vehicle attitude. In general, the vehicle was maintained in a solar inertial attitude, with a -40° to -50° pitch (MDA towards the Sun). This maneuvering kept the OWS internal temperature below about 125°F until just before to SL2 launch.

OWS internal temperature sensors had a maximum calibration limit of 120°F. As sensors went off scale high, it was necessary to estimate their readings by using the ΔT relationship between the off-scale sensors and other ceiling measurements that existed before they went off scale high. For this reason, the OWS SL1 average temperature history during this time should be considered an estimate.

The parasol was deployed by the SL2 crew through the solar scientific airlock on DOY 147 at approximately 0100 GMT. OWS internal temperatures began to drop immediately and reached 80°F 8 days later. After parasol deployment EREP maneuvers and OWS heat exchanger operation produced small (2 to 3°F) temperature variations but beta angle was the most significant perturbing effect on OWS temperature. As beta angle increased, the portion of the orbit that Skylab was in the sun increased until it was in full-Sun for a few orbits to a few days. Skylab entered one of these full-Sun periods at the end of SL2 on DOY 173. When the SL2 crew left, the internal OWS temperature had risen to 83°F and continued to rise to 98°F on DOY 177 when Skylab began to experience orbital night periods again.

Average OWS temperature remained between 78 and 81°F until the twin pole shield was deployed at the end of DOY 219. Because of the additional shading of the gold foil, which reduced the external heat load, the OWS average temperature decreased to 72°F.

OWS film vault temperature profile is shown in Figure 3-7. Temperatures of the film vaults were monitored during each mission using a weighted average of temperature sensors in the vicinity of each vault. Values thus obtained were checked by the crew with a portable surface temperature sensor and the weighting factors adjusted to yield vault temperatures accurate to within a few degrees.

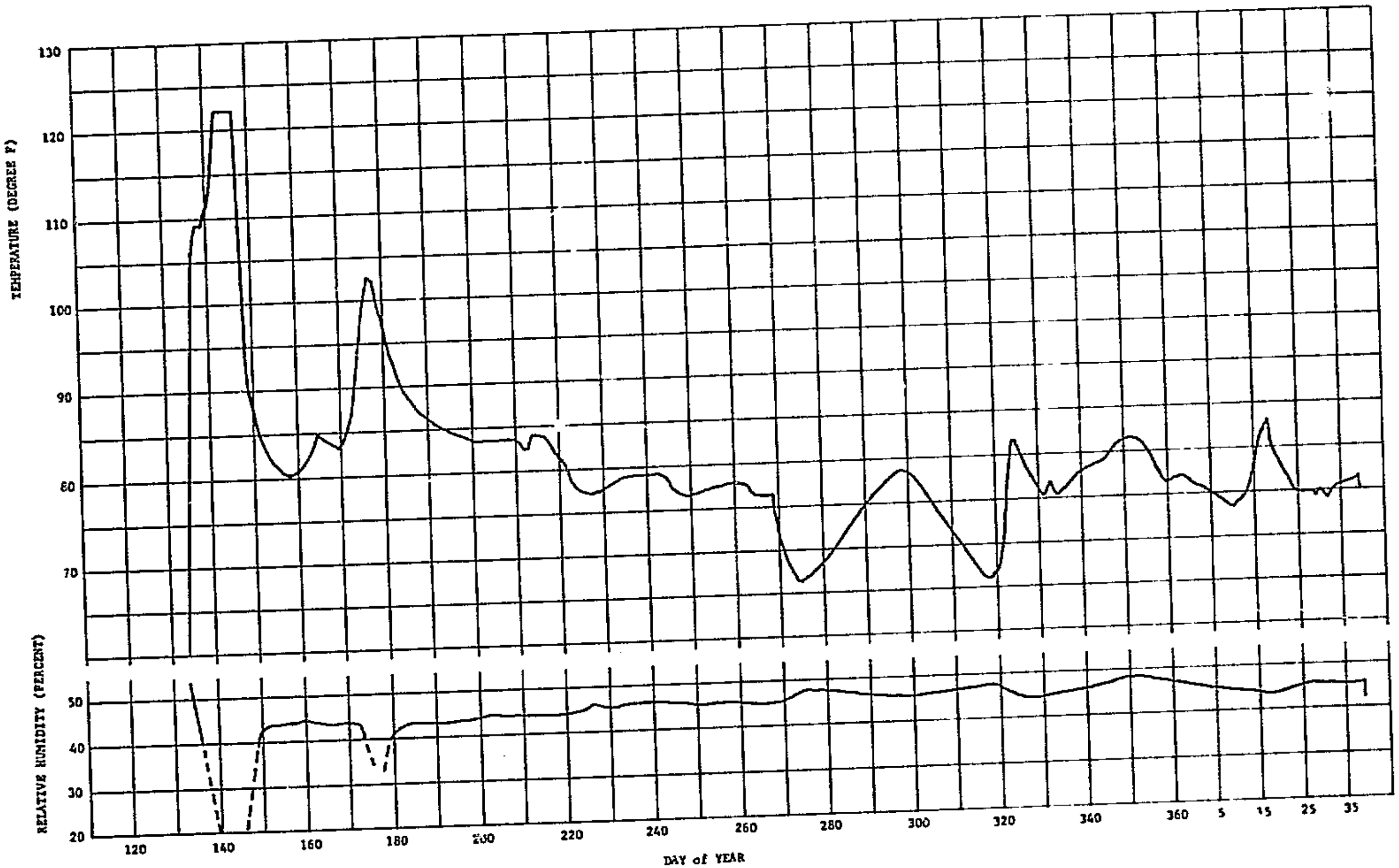


FIGURE 3-7 OWS FILM VAULT TEMPERATURE AND RELATIVE HUMIDITY

The period of high temperature and low humidity at the beginning of the Skylab mission was cause for concern for many of the experiments employing film stowed in the OWS film vault. Results of pre-mission film degradation tests and other data available from Eastman Kodak Co. were reviewed. It was determined that the low humidity, low pressure, nitrogen atmosphere provided near-optimum storage conditions for the elevated temperatures. The potential for color shift caused by temperatures above 120°F indicated that resupply of the EREP visible color and IR films was advisable. In addition, review of previous thermal tests results for SC-5 and 103a-O films led to the same conclusion. Therefore, experiments S019, S183, S190A, and S190B (Ref. 4e) were either partially or totally resupplied with fresh film rolls on SL2. The S009 Nuclear Emulsion Experiment was also identified as requiring resupply, but was delayed until SL4 due to space and weight considerations. The initial S009 package was exposed and returned on SL2, but heat had fused the layers of film, rendering the data unrecoverable.

The maximum film vault temperature of 122°F occurred just before parasol deployment on DOY 147. After parasol deployment, the vault cooled to the low 80s and remained there until the higher beta angles at the end of the SL2 manned missions. During the full sunlight period at the beginning of the SL2/SL3 storage period, the film vault reached approximately 100°F before cooling down to the low 80s again. During the remainder of the Skylab mission, film vault temperature was below 80°F except for short periods of high beta angle during SL4.

While the films were in the cameras, temperature and humidity depended on the operational environment of the camera. EREP films used in the MDA remained at "room" temperatures and were out of the OWS film vault for only short periods. Some Scientific Airlock (SAL) experiments viewed through windows (e.g., S063 and S190B), thus maintaining OWS temperature. Others were vented to the outside and operated in a vacuum (e.g., S019 and S020). Temperatures for these experiments were inferred from temperatures of surrounding equipment, preflight analyses, and test data because temperature sensors were not integral with most SAL experiments.

3.2.2 MDA Temperature History

The MDA average internal temperature history is presented in Figure 3-8. MDA temperatures before SL2 were influenced by the vehicle attitude changes associated with thermal management of the OWS, and by management of MDA wall heaters to conserve power. These factors resulted in MDA temperatures between 50 and 65°F before SL2. Low MDA internal temperatures were maintained during SL2 by operating the MDA wall heaters only intermittently. This conserved power before solar-array panel deployment on DOY 158 and provided a cooler interchange flow with the OWS after solar-array panel deployment. Internal temperatures were approximately 47°F during both the SL2/SL3 and SL3/SL4 unmanned storage periods.

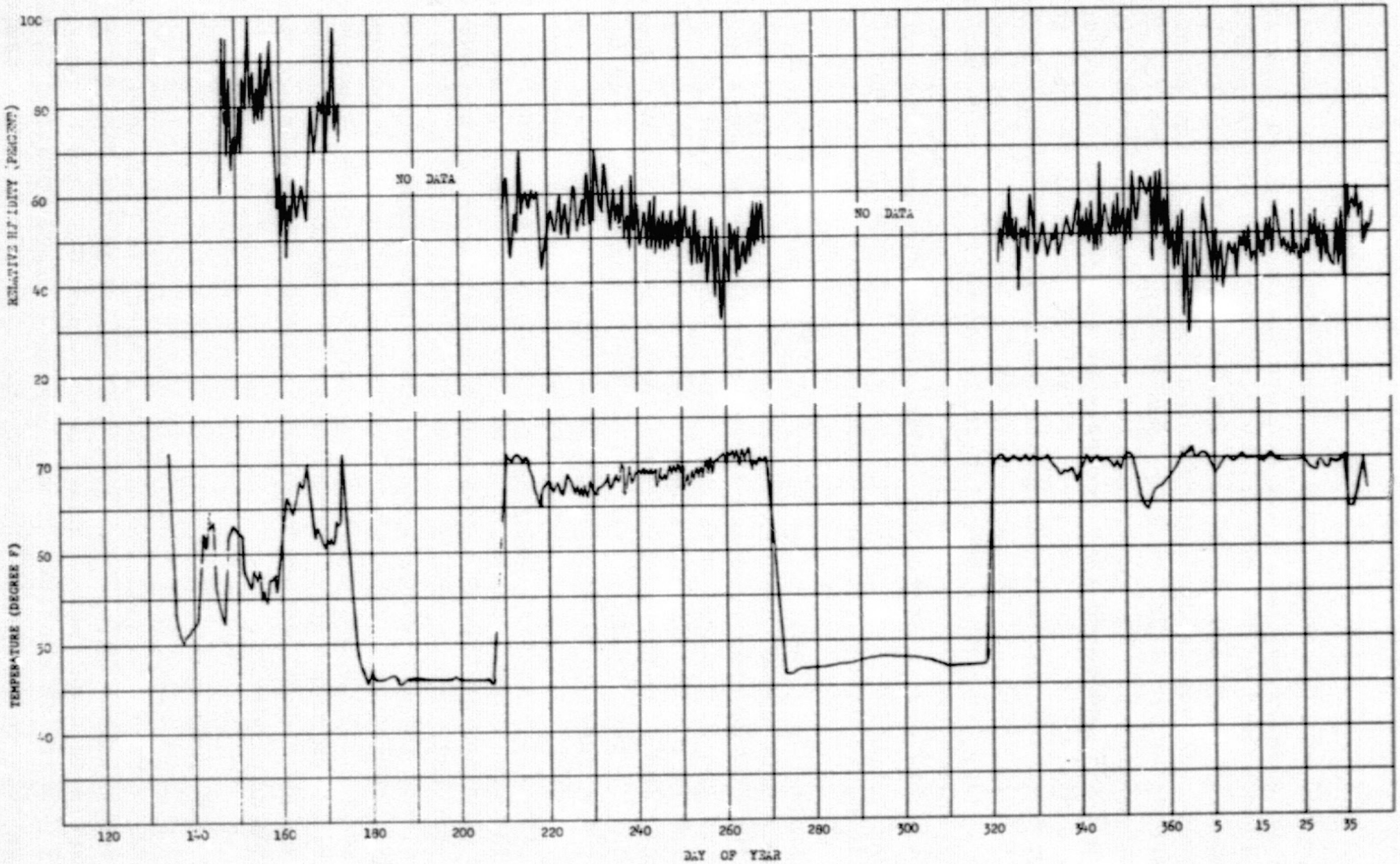


FIGURE 3-8 MDA AVERAGE INTERNAL TEMPERATURE AND RELATIVE HUMIDITY

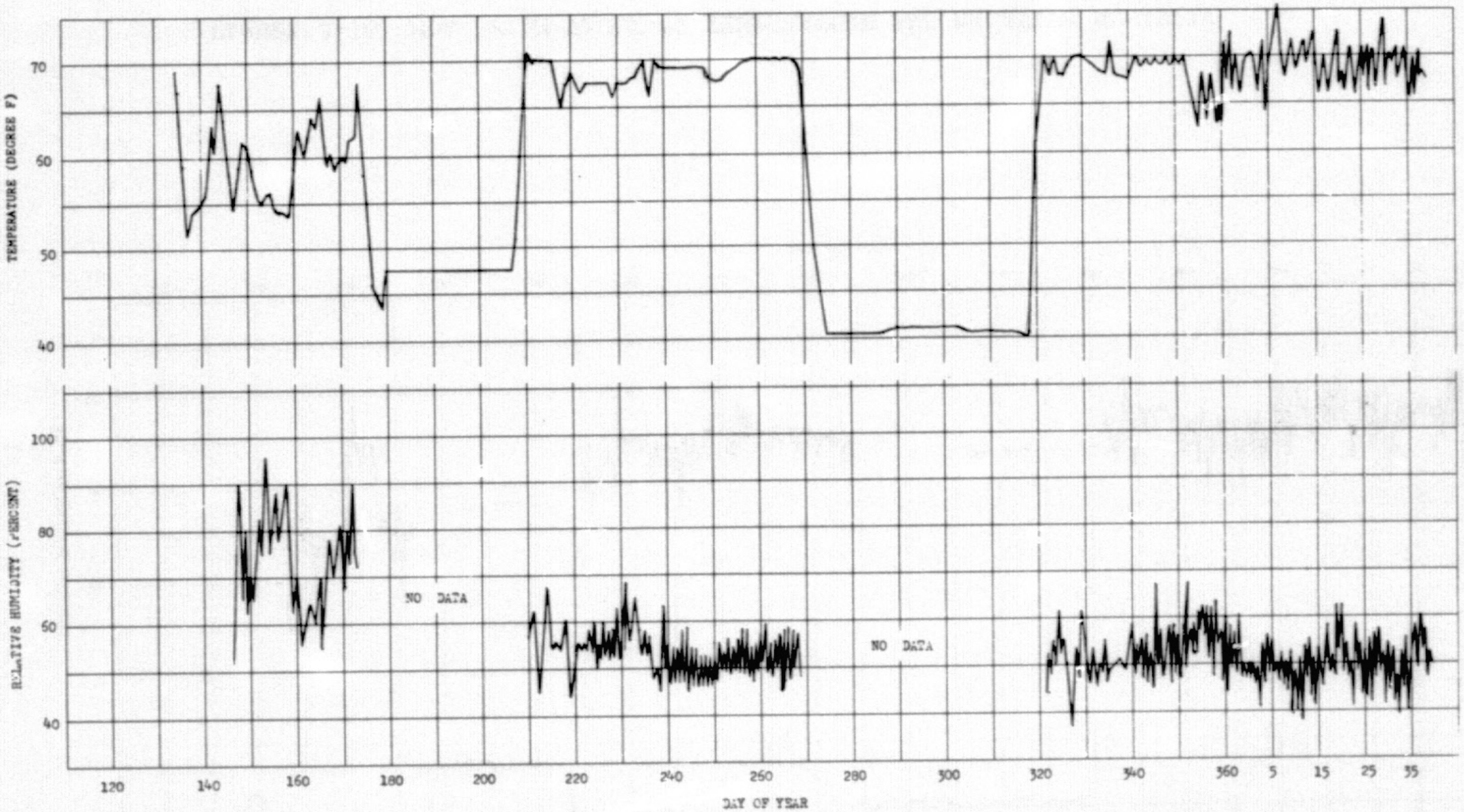


FIGURE 3-9 MDA FILM VAULTS #1 and #4 TEMPERATURE AND RELATIVE HUMIDITY

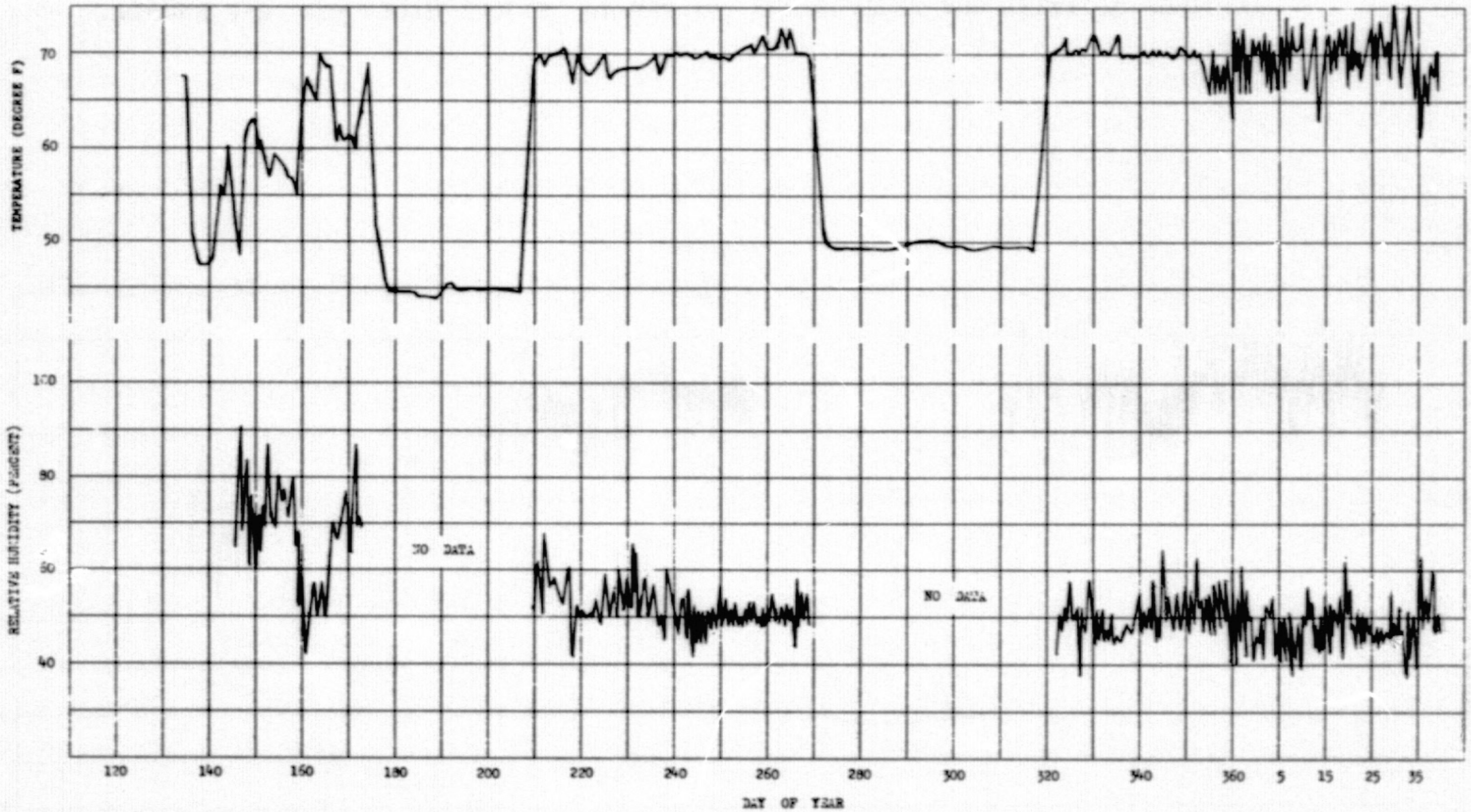


FIGURE 3-10 MDA FILM VAULT #2 TEMPERATURE AND RELATIVE HUMIDITY

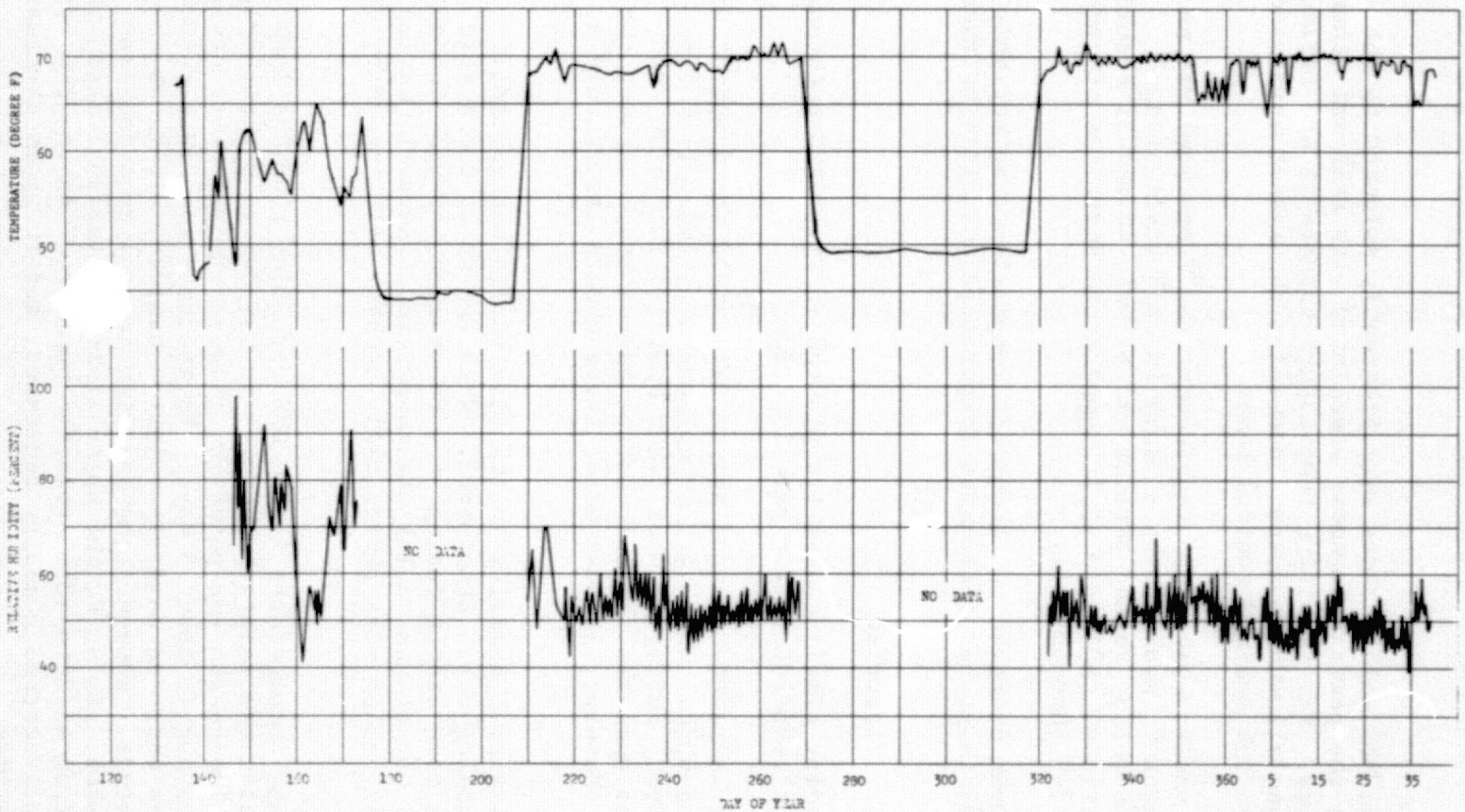


FIGURE 3-11 MDA FILM VAULT #3 TEMPERATURE AND RELATIVE HUMIDITY

During SL3 and SL4, MDA wall heaters were frequently switched to the 45°F thermostat setting for power management associated with EREP and other experiment maneuvers. The resulting temperature transients are reflected in Figure 3-8. When allowed to operate normally, the system maintained temperatures within the desired control range.

The MDA film vault temperature requirement (80°F maximum) was met. Film vault temperatures, measured by sensors in each vault, ranged between 48 and 76°F during manned periods and between 44 and 71°F during orbital storage periods. MDA film vault temperature histories are presented in Figures 3-9 through 3-11.

Most ATM cameras operated in vacuum but temperature was actively controlled to maintain proper instrument temperature and minimize thermal gradients.

3.2.3 Humidity Histories

Relative humidity timeline data are plotted in Figures 3-6 through 3-11 along with the temperature for each location.

The atmosphere moisture control system maintained the dewpoint within a range of 46 to 60°F. Temporary exceptions occurred during EVA, when humidity dropped; during showers, when humidity increased, and during some periods when the thermal control valves stuck causing the humidity to drop. However, in each case, these events lasted only a few hours.

During the missions, humidity in the film vaults was generally that of the surrounding cabin atmosphere. When the vault doors were closed, the normal mode except during film removal or stowage, the movement of air in and out of the vaults was restricted. However, during manned periods, the vaults were periodically opened, allowing entry of cabin atmosphere.

Because of high temperatures in the OWS resulting from the loss of the meteoroid shield, the relative humidity in the OWS film vault dropped rapidly after SL1 launch and the potassium thiocyanate pads were estimated to have dried out in about 5 days. Potassium thiocyanate desiccant absorbs or releases water to maintain relative humidity within about $\pm 1\%$ at a given temperature. However, the humidity control band decreases as temperature increases. At 90°F, the upper limit of available data, the control band was from 41.2 to 42.6% relative humidity. As the OWS temperatures increased, control humidity decreased, and the pads eventually lost all their moisture.

It was feared that the low humidity would dry out the film to the point that emulsion cracking and static discharge might become problems.

It was suggested that water might be introduced to the film vault through the use of a moist towel, thus raising the humidity and allowing reconstitution of the film. However, the final decision was that the rise in humidity due to activation of Skylab and the period of time between activation and anticipated film use would be adequate for reconstitution.

During unmanned orbital storage the relative humidity of films stowed in the OWS film vault was controlled to 45 $\pm$15% by the potassium thiocyanate pads in the vault doors. These pads were sized to maintain proper humidity in the OWS film vault during a 60-day storage period and were reconstituted during SL2 and SL3.

The relative humidity in the MDA film vaults followed that in the MDA during the manned missions, except for variations due to the slightly different temperature at the specific film vault locations. The humidity in the MDA was high during SL2 because of the low temperatures maintained for power conservation and to aid in temperature control of the OWS. Although the relative humidity in the MDA approached 100% several times during SL2, no condensation was reported by the crew. Relative humidity in the MDA during the storage periods was unknown because the humidity control system was deactivated. It was expected to be relatively high after SL2 because of the reduced temperature with no change in gas composition and conversely to be relatively low after SL3 because of the repressurization with dry gas after a brief reduction to 2.0 psia. Some of the ATM films were not exposed to MDA humidity because they were sealed in canisters filled with dry nitrogen.

3.2.4 Pre- and Postflight Environments

Environmental control of the films was provided during all periods from applying the preflight sensitometry through postflight processing. In some cases, this included refrigeration for substantial storage periods. However, in almost every case, some periods were encountered during which ambient room temperature and humidity conditions prevailed (approximately 70°F and 50% RH). While films were in their launch modules, the environment was controlled by ground support equipment. After loading for launch, the ATM films stowed in the MDA and those installed in cameras were in a dry nitrogen atmosphere. In the Vertical Assembly Building, the OWS atmosphere was maintained at 45 $\pm$5°F and 50% relative humidity. After rollout to the launch pad, the OWS was also purged with nitrogen, which maintained the same film vault temperature. However, the relative humidity inside the OWS film vault was then maintained at approximately 45% by the potassium thiocyanate salt pads, as it was during orbital storage periods.

During recovery, the environment in the Command Module was uncontrolled until it was loaded on the aircraft carrier. However, all Skylab reentries were on target and the Command Modules were on deck

in 40, 42, and 40 minutes, respectively, for SL2, SL3 and SL4 (Ref. C.2, C.3 and C.4). Film off-loading from the Command Module was completed within 4 hours 29 minutes for SL2, 8 hours 25 minutes for SL3, and 8 hours 44 minutes for SL4. After removal from the Command Module, the films were maintained in ambient room conditions (70 $\pm 10^{\circ}F$ and 25 to 60% RH) during transportation to Houston and while at Houston awaiting processing.

3.3 Environmental Timelines

Environmental timelines were formulated for each type of film documented in this report. A separate timeline was prepared for each film load or magazine analyzed because different loads or magazines were exposed to substantially different environments, particularly when used on different missions. Each timeline was derived from general Skylab environmental data discussed in the preceding paragraphs, plus specific operational environmental data for the particular experiment and preflight and postflight handling peculiar to that film roll. Each timeline represents the best available information about the environmental exposure of each load or magazine of each type of film. The timelines were used in analysis of each film type, discussed in Section 4.

A sample timeline is shown in Figure 3-12. At the top, each chart defines the film type, roll number, and experiment on which the film was used. Timelines are presented as graphic plots showing histories of radiation dose in rads-air, temperature in degrees Fahrenheit, and relative humidity in percent along a common time base. Below the plots, significant film events are listed by date and cover the period from application of preflight sensitometry to postflight processing. Also noted on the timeline is the total radiation dose (upper right-hand corner) for that film roll. Peculiar environments to which the film was exposed (e.g., vacuum or nitrogen storage) are identified by coded lines defined in the legend.

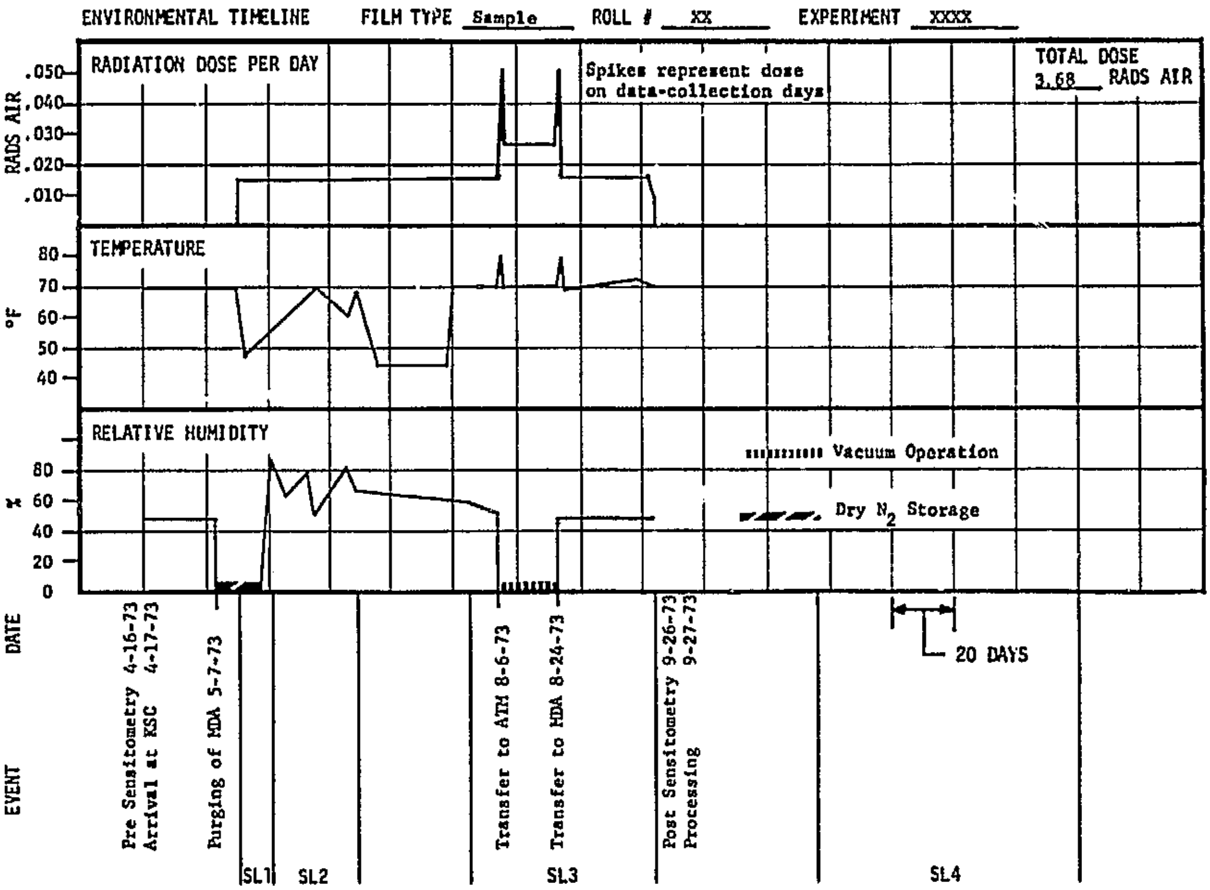


FIGURE 3-12 SAMPLE TIMELINE

4. ENVIRONMENTAL EFFECTS ON SKYLAB FILM

Evaluation of environmental effects was accomplished by first collecting and compiling the available data for each film type. These data included flight film environmental history and sensitometric curves, ground-control film data, and pre-mission test data. The compilation identified 411 rolls or carrousels of film that were launched and 375 that were returned. The 36 rolls that remained in Skylab were replaced with fresh film or discarded as a result of experiment rescheduling and projected thermal degradation from the high workshop temperatures encountered before the parasol deployment on SL2.

The compiled Skylab film data were analyzed, and representative rolls of each type of film for each Skylab mission were selected for detailed evaluation and presentation. Table 4-1 summarizes the data compiled and identifies the number of rolls for which data are presented. The table also identifies film size and the missions on which the rolls selected were launched and returned.

Note that, although 375 rolls of film were returned, fewer than 175 of these had the pre-flight, post-flight, and control sensitometry data required for complete evaluation of environmental effects.

Analysis of the environmental effects on the film was based on the effect that storing and using a film in the Skylab environment had on the Hurter and Driffield (H & D) curve for that film. The H & D curves (also referred to as the sensitometric curves) were derived from density measurements of step wedge images placed on the flight and control films. These data were obtained directly from principal investigators and references 5a through 5f. The H & D curves provide the response of each film roll in terms of film density resulting from a given exposure for the particular processing procedure used. To simplify analysis of environmental effects, families of H & D curves from several related sensitometric exposures were plotted on single pages. Figure 4-1 illustrates a typical family of H & D curves for a black-and-white negative film, and Figure 4-1b illustrates an H & D curve family for a color reversal film. The curves are identified by labels that indicate the environment associated with each curve. Definitions associated with each label used in this memorandum are:

FLIGHT PRE - Sensitometric exposure applied to the head of the flight film roll before the Skylab mission on which the roll was launched. Film was stored in the Skylab environment shown on the environmental timeline chart. Curve is used to determine latent image effects.

TABLE 4-1 DATA COMPILATION SUMMARY

FILM TYPE	FILM SIZE	NUMBER OF ROLLS LAUNCHED	NUMBER OF ROLLS RETURNED	ROLLS SELECTED FOR REPORT NUMBER	LAUNCH	RETURN
NTB3	35 mm	3	3	3	SL4	SL4
104-06	magazines	10	10	+		
SC-5	carrousel of plates	3*	3	1	SL1	SL2
				1	SL2	SL2
				1	SL4	SL4
101-05	carrousel of plates	2*	2	2	SL4	SL4
101-06	canister of plates	6	5	+	SL2	SL2
					SL3	SL3
					SL4	SL4
	plate	1*	1	+		
	drum magazine	2	2	+		
103a-0	carrousel of plates	1*	1	1	SL4	SL4
	16 mm	4	4	1	SL1	SL2
				1	SL2	SL2
				1	SL3	SL3
SO-101	35 mm	5	5	2	SL1	SL3
				1	SL1	SL4
3414	35 mm	1	0	+		
	5 in	3	3	1	SL1	SL2
				1	SL3	SL3
				1	SL4	SL4
SO-212	35 mm	4	4	1	SL1	SL2
				2	SL1	SL3
				1	SL1	SL4

*<u>NOTE</u>: S183 Carrousel 1-1 flown on SL4 contained:
19 plates of 103a0
10 plates of 101-05
6 plates of SC-5
1 plate of 101-06

\+ Sensitometry data not available.

TABLE 4-1 DATA COMPILATION SUMMARY (CONT'D)

FILM TYPE	FILM SIZE	NUMBER OF ROLLS LAUNCHED	NUMBER OF ROLLS RETURNED	ROLLS SELECTED FOR REPORT NUMBER	LAUNCH	RETURN
SO-212	70 mm	5	5	1	SL1	SL2
				1	SL1	SL3
				1	SL1	SL4
SO-022	70 mm	32	30	2	SL1	SL2
				2	SL2	SL2
				4	SL3	SL3
				4	SL4	SL4
026-02	35 mm	5	5	2	SL1	SL3
				1	SL1	SL4
3401	16 mm	2	2	2	SL1	SL2
	35 mm	4	4	2	SL4	SL4
SO-265	35 mm	12	8	3	SL4	SL4
2485	16 mm	6	3	2	SL1	SL2
	35 mm	22	19	2	SL3	SL3
				2	SL4	SL4
2424	70 mm	32	30	2	SL1	SL2
				2	SL2	SL2
				4	SL3	SL3
				4	SL4	SL4
SO-242	35 mm	1	1	1	SL4	SL4
	5 in	10	9	1	SL1	SL2
				2	SL3	SL3
				2	SL4	SL4
SO-356	70 mm	17	15	2	SL2	SL2
				2	SL3	SL3
				2	SL4	SL4
SO-368	16 mm	9	8	2	SL2	SL2
				2	SL3	SL3
	35 mm	36	35	+		

+ Sensitometry data not available.

TABLE 4-1 DATA COMPILATION SUMMARY (CONCL'D)

FILM TYPE	FILM SIZE	NUMBER OF ROLLS LAUNCHED	NUMBER OF ROLLS RETURNED	ROLLS SELECTED FOR REPORT NUMBER	LAUNCH	RETURN
	70 mm	17	17	2	SL1	SL2
				2	SL2	SL2
				2	SL3	SL3
				3	SL4	SL4
SO-168	16 mm	100	91	2	SL1	SL2
				2	SL1	SL3
				2	SL1	SL4
	35 mm	28	27	+		
2443	35 mm	8	8	+		
	70 mm	17	15	2	SL2	SL2
				2	SL3	SL3
				2	SL4	SL4
3443	16 mm	1	1	+		
	5 in	2	1	1	SL3	SL3
SO-131	5 in	1	1	1	SL4	SL4
3400	35 mm	2	0	0		
TOTALS		411	375	114		

\+ Sensitometry data not available.

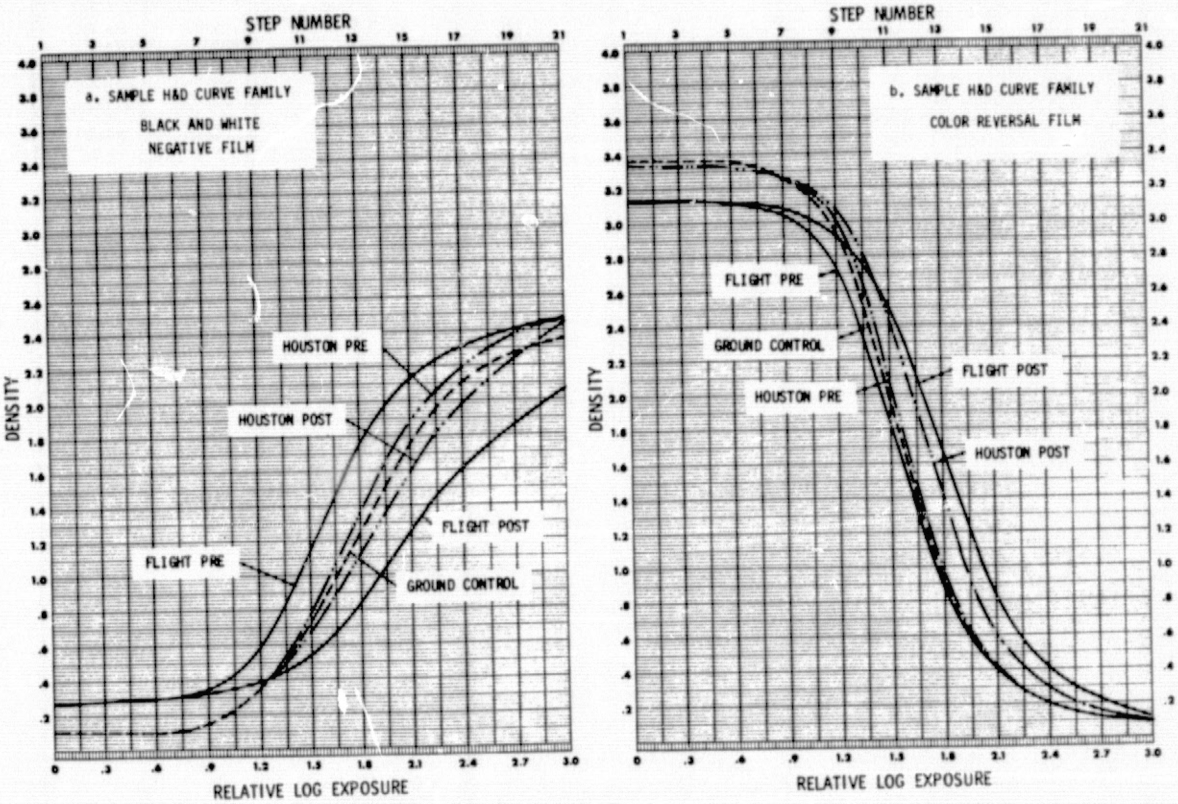


FIGURE 4-1. SAMPLE H & D CURVES

POST FLIGHT - Sensitometric exposure applied to the head of the flight film roll after the film was returned from orbit and before processing. Film was stored in the Skylab environment shown on the environmental timeline chart. Curve is used to determine change in film sensitivity.

CONTROL - Sensitometric exposure applied to the head of the same emulsion batch as the flight film at the same time as FLIGHT POST. This film was stored in a refrigerated film storage vault controlled to a 45 $\pm$ 2°F and 45 $\pm$ 10% relative humidity and processed with flight film. Processing was adjusted to keep the controls as constant as possible from roll to roll and mission to mission. Curve is used as a fresh film standard.

GROUND CONTROL - Same as CONTROL, except that the film was stored frozen (approximately 0°F). Frozen storage applied to most infrared and spectroscopic films.

HOUSTON PRE - Sensitometric exposure applied to film of the same emulsion batch as the flight film at the same time as FLIGHT PRE. This film was stored at ambient room conditions (72 ± 5°F and 45 ± 10% relative humidity) at JSC Photographic Technology Division and processed with the flight film. Curve is used to approximate Skylab temperature and relative-humidity latent-image effects and thereby isolate ionizing radiation effects.

HOUSTON POST - Same as HOUSTON PRE, except the sensitometric exposure was applied at the same time as FLIGHT POST. The curve is used to evaluate changes in sensitivity.

FLIGHT HEAD - Sensitometric exposure applied to the head of the flight film roll with an in-flight sensitometer during the first data take on that roll.

FLIGHT TAIL - Sensitometric exposure applied to the last frame of the flight film roll with an inflight sensitometer during the last data take with that roll.

GROUND CONTROL PRE - Same as the GROUND CONTROL, except the sensimetric exposure was made at the same time as FLIGHT PRE.

The H & D curve families are presented with the environmental timeline charts by film type in Appendix D. The curves for color reversal films are presented for red, green, blue, and visual density measurements. Density measurements taken with the red, green, and blue filters provide for evaluation of the environmental effects on each emulsion layer of the color film. The visual filter data indicate the overall effects observed in the spectral region similar to that to which the human eye responds.

The H & D curves were analyzed to quantify the effects of spacecraft environment in terms of increases in base plug fog and reduction of maximum density. Environmental effects on the latent image and film sensitivity were both quantified and evaluated to separate the effects of ionizing radiation from those of storage time, temperature, and relative humidity.

Environmental effects on base plug fog or maximum density for color film were evaluated by taking the difference between the flight-film base plus fog or maximum density and that of the control film. These data were then tabulated with the calculated flight radiation dose estimate,

pre-mission predicted radiation dose projection, and associated predicted change in base plus fog or maximum density.

Environmental effects on the latent image and film sensitivity were analyzed by first determining the relative log exposure value for each H & D curve in the curve family at densities of 0.6 and 1.2 above fog. Selective calculations of differences in these log exposure values quantify the change in film response at these densities in terms of log exposure, which is related to f number by:

0.15 log exposure = ½ f-stop;
0.30 log exposure = 1 f-stop.

The differences calculated and their relevance to the environmental effects are:

CONTROL minus FLIGHT PRE - Latent image change due to total Skylab environment on prelaunch exposure;

CONTROL minus HOUSTON PRE - Latent image change due to ambient room-temperature storage for period of the mission on a prelaunch exposure. This approximates the storage time, temperature, and relative humidity effects on the flight film to the extent of environmental similarity. (Good for SL3 and SL4, poor for SL1 and SL2 films stored in the OWS). It does not, however, account for any effects which may have been caused by the increased oxygen content of the Skylab atmosphere (70% O_2, 30% N_2).

HOUSTON PRE minus FLIGHT PRE - Approximates the latent image change due to Skylab ionizing radiation. Accurate to the extent of environmental similarity of the CONTROL minus HOUSTON PRE discussed above.

TEST CONTROL minus TEST - Comparative data from pre-mission testing of temperature and humidity latent-image* effects. Based on film tests in environments of 100°F, 20% RH for 28 days for comparison to SL1 and SL2, and 80°F, 50% RH for 56 and 84 days for SL3 and SL4. These data provide relative comparison only due to differences in the test and mission environmental conditions.

*No pre-mission film sensitivity effects test data were available for comparison.

CONTROL minus FLIGHT POST - Total change in film sensitivity due to the total Skylab environment for the applicable mission.

CONTROL minus HOUSTON POST - Approximate film sensitivity change due to storage time, temperature, and relative humidity; applicable to the same conditions and constraints as the CONTROL minus HOUSTON PRE discussed above.

HOUSTON POST minus FLIGHT POST - Approximately film sensitivity change due to Skylab ionizing radiation, with the limitation discussed under HOUSTON PRE minus FLIGHT PRE above.

The remainder in each of these calculations gives both the magnitude of the change and direction of shift of the film response curve. A negative remainder indicates a loss in the quantum efficiency of the film, while a positive remainder indicates an increase in quantum efficiency.

Ratios of the remainders of these calculations also provide the percentage of overall environmental effects caused by radiation dose compared to storage time, temperature, and relative humidity. The ratios used in this evaluation were:

$$\frac{\text{CONTROL - HOUSTON (PRE or POST)}}{\text{CONTROL - FLIGHT (PRE or POST)}} \times 100 = \text{\% effect due to storage time, temperature, and relative humidity.}$$

$$\frac{\text{HOUSTON (PRE or POST) - FLIGHT (PRE or POST)}}{\text{CONTROL - FLIGHT (PRE or POST)}} \times 100 = \text{\% effect due to ionizing radiation.}$$

These calculations were subject to the same accuracy limitations defined for input parameters.

In the subparagraphs of this section, results of the analysis of H & D curves and comparison of these results to pre-mission test predictions are discussed for each film type. The comparative analyses were based on the pre-mission test data reported in reference 6a through 6k. These data include results of environmental testing of several of the same types of film as flown on Skylab and some related film types. For the most part, pre-mission tests were designed to measure film response to a single environmental parameter: ionizing radiation (CO^{60} gamma rays or protons), temperature, relative humidity, or vacuum. Some limited simulations of projected Skylab environments and timelines were also performed. Table 4-2 summarizes test data available for each Skylab film by environmental parameter. Note that, although

TABLE 4-2. SKYLAB PRE-MISSION TEST DATA AVAILABLE

FILM TYPE	RADIATION	TEMPERATURE	HUMIDITY	VACUUM
NTB3				
104-06	SWR	104-01	104-01	SWR
SC5	SC5	SC5	SC5	
101-05	101-01	101-01	101-01	
101-06	101-01	101-01	101-01	
103a-0	103a-0			
SO-101	SO-392			
3414	3414			
SO-212	SO-114	SO-114	SO-114	3400
SO-022	3400	3400	3400	
026-02	3400	026-02	026-02	
SO-265				
2485	2485	SO-166	SO-166	
2424	2424	SO-246	SO-246	
SO-242	SO-242			
SO-356	SO-242	SO-121	SO-121	
SO-368	SO-368	SO-368	SO-368	
SO-168	SO-168	SO-168	SO-168	
2443	2443	SO-180	SO-180	
3443	SO-180	SO-180	SO-180	
SO-131				

related film types were used in the comparative analyses, there were usually minor differences between these films and Skylab films. Therefore, the comparisons are useful to analyze trends but may not be valid in an absolute sense.

4.1 Performance Evaluation, Film Type 088-03 (NTB3)

This special film incorporated a thin NTB3 nuclear emulsion to record 20-V electron images in the Lyman-alpha wavelength of Comet Kohoutek and far-ultraviolet magnitude of stars. The special electrographic camera used for this experiment and early results of the experiment data analysis are described in reference 4i. Three 30-ft rolls of film were flown on SL4. Dr. Thornton Page, Principal Investigator, said that Type 088-03 (NTB3) had very good quantum efficiency (25%) and was adequate in fulfilling S201 experiment requirements. However, about 25% of the exposed photographic frames were degraded by random localized film fogging. The fogging was very dense and appeared to be caused by electrostatic flashes at the film surface during camera operation. This conclusion was based on three factors. First, the interior of the camera and therefore the photographic film were purposely dehydrated to prevent degradation of the camera photocathode. Second, the presence of high voltage (20Kv) in the camera provided a potential charging mechanism. Third, the gamma of the film in the visible region was very high ($\sim$ 160), and, therefore, an electrostatic flash bright enough to expose the film would cause a localized high-density image.

4.1.1 Environmental Analysis Results, NTB3

Sensitometric step wedge images on the NTB3 flight film were limited to visible-light exposures for processing controls. Sensitometric images using 20Kv electron radiation, as was the case for in-flight data recording, were not available due to the difficulty and operational impact of providing such imagery. Environmental timelines and sensitometric curves from visible-light exposure for the three NTB3 flight rolls are given in Appendix D, Figures D-1 through D-3. It should be emphasized that these curves do not represent the response of the film in the spectral region of use, i.e., 20Kv electrons. This is illustrated by the difference in slope of these curves for the two different spectral regions. The slopes or gamma for the visible-light curves given in Figure D-2 and D-3 are 160, while the slope derived from flight-data analysis of 20Kv electron exposures was on the order of 1 to 3. However, the visible light data are presented because sufficient 20Kv electron data were not available, and the visible light data do provide environmental effect data that may be related to future applications of this type of film.

The H & D curves in Figures D-2 and D-3 show an increase in fog due to the total Skylab environment of 0.34 to 0.42 density units and a

reduction of maximum density of 1.12 density units compared to the control-film curve. This reduction of maximum density reduced the density range of the film for visible light by about 1/3. However, scientific data were recorded in this upper third of the film density range, indicating that this reduction of maximum density was not applicable to 20Kv electron exposures.

TABLE 4-3 ANALYSIS RESULTS, FILM TYPE NTB3

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
1	+	1.63	+	0.36
2	+	1.68	+	0.34
3	+	1.69	+	0.42

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1	-0.07	-0.05	-0.23	-0.23	0.16	0.18	+	+
2	-0.07	-0.04	-0.09	-0.08	0.02	0.04	+	+
3	-0.04	0	-0.14	-0.11	0.10	0.11	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1	0.08	-0.06	0.12	0.09	-0.04	-0.15
2	0.20	0.16	0.13	0.16	0.07	0
3	0.17	0.21	+	+	+	+

+ No data available.

Quantitative analysis results are presented in Table 4-3. Radiation data show an apparent discrepancy between the radiation dose and the fog level for Roll 2. However, the lower fog on this roll is attributed to the roll being under vacuum for only a short time relative to the other two rolls. Therefore, because vacuum storage causes a slight increase in sensitivity, the average sensitivity to ionizing radiation over the total period of the mission was slightly less, resulting in a lower fog.

Latent image effects show latent image facing due to storage time, temperature, and humidity to be greater than the overall effect, with the radiation effect partially (or totally in one case) cancelling out the facing loss with a density increase. The net effect was a small (less than 1/4 f-stop) latent-image loss. Again, the effects for Roll 2 were less dynamic, even though the net effect was about the same as for Roll 1.

Film sensitivity results show a similar opposing effect between temperature, humidity, and radiation for Roll 1, but an additive effect for Roll 2. The net result shows an increase in sensitivity ranging from 1/2 to 2/3 of an f-stop.

No comparison was made because no test data were available for this film.

4.2 Performance Evaluation, Film Type 104-06

Photographic detection and quantification of vacuum ultraviolet radiation is difficult due to the strong absorption of this radiation in the gelatine used to protect and hold photosensitive silver halide crystals. Kodak Special Film, Type 104-06, is a Schumann-type emulsion, similar to Kodak SWR, developed to make photographic recording of this radiation feasible. This type of emulsion is manufactured with a monolayer of silver halide crystals held in place by an even thinner layer of gelatine. Therefore, some of the silver halide crystals protrude from the gelatine. These films have no gelatine overcoat and are consequently extremely sensitive to abrasion, pressure sensitization, and chemical fogging. Other Schumann-type emulsion films used on Skylab were Types SC-5, 101-05 and 101-06. SC-5 is similar to 104-06 in film speed but is manufactured by Kodak Pathe in France and coated using a different technique. Special order films 101-05 and 101-06 are about 10 times faster than 104-06 and are manufactured by the Kodak Research Laboratory, Rochester, N.Y.

Type 104-06 was used on Skylab Experiments S082A (Extreme Ultraviolet Spectroheliograph), and S082B (Spectrograph and Extreme Ultraviolet Monitor). These experiments employed film carrousels that transported film strips mounted in individual film holders. This technique was used to eliminate the possibility of film abrasion. Experiment S082A used six carrousels, two on each Skylab mission. S082B used four carrousels one each on SL2 and SL4 and two on SL3. Because of the relatively small quantity of film manufactured in a given film batch, several film batches were used during the Skylab missions. Therefore, film data are identified as 104-06-XX, in which the last two digits give the batch number. Batch to batch variation was both expected and observed.

Performance of this film in these Skylab applications was judged to be good by the experiments principal investigator, Dr. R. Tousey. Some analytical difficulty was encountered due to batch-to-batch variation. Larger quantities of film with good uniformity between batches are desirable. Some unpredicted fog was observed, even though radiation levels were lower than anticipated. Fogging and desensitization streaks were observed on SL2 and SL3 films in areas where the film was adjacent to structural ridges in the stainless-steel film holder. The configuration of the film, film holder and film streaks are illustrated in Figure 4-2.

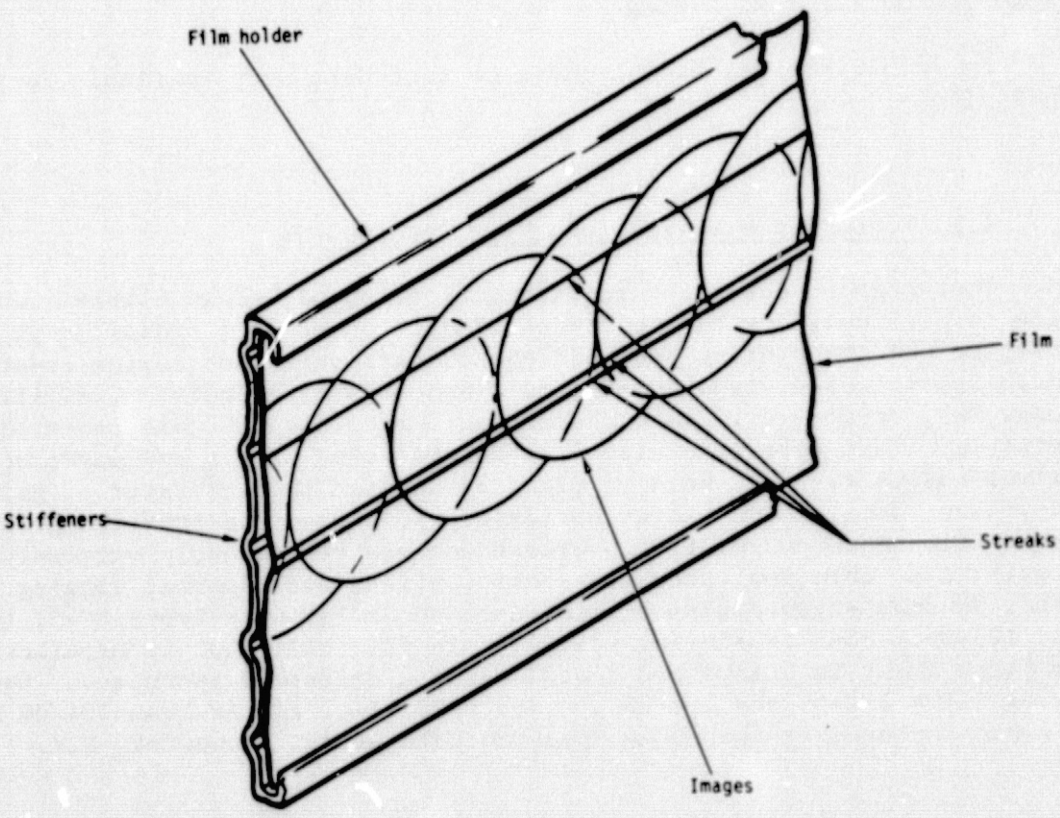


FIGURE 4-2. EXPERIMENT S082A FILM STREAKS

This phenomenon could not be duplicated in pressure, stress, nor environmental testing. However, the problem was corrected on SL4 by switching to unribbed anodized aluminum film holders. The cause of this anomaly is still undetermined. Aluminum used near this film must be anodized because contact with bare aluminum causes the film to fog.

The most dynamic effect of storing and using this film on Skylab was a reduction of maximum density. The change in maximum density was greatest for SL2 data, improved on SL 3, and was even less on SL4.

To eliminate chemical fogging, special precautions were taken in handling this film. Naval Research Laboratory (NRL) personnel who handled and processed the film applied many years of experience and testing to establish these procedures. The procedures controlled both known and unknown sources of chemical fogging, including clothing and chemically treated fabrics and personal items such as after-shave lotion, deodorant, hair spray, and cosmetics.

Because of the unique nature and application of this and other Schumann-type emulsions, their use on future space programs is certain to continue. Therefore, more research and testing of this type of film are highly recommended.

4.2.1 Environmental Analysis Results, 104-06

Type 104-06 film was evaluated on a representative sample basis. Environmental timelines and H & D curves used for analysis are given in Appendix D, Figure D-4 through D-10. The curves provide representative data for Carrousels A-1, A-2, A-2*, A-5, B-1, B-2, and B-3 and illustrate data for each Skylab mission for S082A and all but SL4 for S082B. The "Representative Control" curves provide composite data from several fresh film receipt samples of that emulsion batch. The "Flight" curves are based on reduction of a representative flight film plate used to record solar data. Data points were derived from different relative exposures of a common solar image point or data area taken at selected exposure times. This derivation assumed a film reciprocity of 1.0. Data were recorded using 170- to 180-nm radiation, except for Carrousels A-2, A-2* and A-5 "Flight Curves," which were exposed with radiation at 30.4 nm. Figure D-8 also shows a "Post-Mission Control" derived from samples kept at 40°F throughout the mission. These curves show a typical difference observed between fresh film receipt data and "Ground Control" (40°F) data.

*Replacement load for original A-2 load used during SL2 instead of during SL3 due to malfunction of A003 camera.

TABLE 4-4. ANALYSIS RESULTS, FILM TYPE 104-06

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
A-1	+	0.81	< 0.01	0
A-2	+	0.74	< 0.01	0
A-2*	+	0.96	< 0.01	0.02
A-5	+	1.66	< 0.01	0
B-1	+	0.84	< 0.01	0
B-2	+	1.90	< 0.01	0
B-3	+	2.32	0.01	0

b. LATENT IMAGE/SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.3 ABOVE FOG	0.6 ABOVE FOG	0.3 ABOVE FOG	0.6 ABOVE FOG	0.3 ABOVE FOG	0.6 ABOVE FOG	0.3 ABOVE FOG	0.6 ABOVE FOG
A-1	0.06	-0.14	+		+		-0.10**	-0.18**
A-2	-0.04	-0.17	+		+			
A-2*	-0.14	-0.07	+		+			
A-5	-0.22	-0.51	+		+			
B-1	-0.23	-0.21	+		+			
B-2	-0.10	-0.68	+		+			
B-3	-0.08	-0.27	+		+			

* Substitute roll for original A-2
** Based on pre-mission test data, 84 days at 80°F and 50% R.H.
\+ No data available

Analysis of the H & D curves showed no measurable fogging due to ionizing radiation. Results of the H & D curve analysis are tabulated in Table 4-4. Of the film evaluated, only that for Carrousel A-2* showed any increase in base plug fog. On the other hand, all flight film plotted showed a loss in maximum density. This reduced the density range of these film samples by 16 to 35%. The change in film response at densities of 0.3 and 0.6 fog are tabulated under "Flight Film Data" in Table 4-4b. This change in film response could not be separated into image fading losses and film sensitivity changes because the date of exposure of the flight data was not available.

*Replacement load for original A-2 load used during SL2 instead of during SL3 due to malfunction of A0ύ3 camera.

4.2.2 Comparison of Flight and Test Data, 104-06

Quantitative comparison of flight radiation fogging, Table 4-4a, and pre-mission radiation test data for SWR was not possible due to the low radiation doses. However, the threshold for fogging does appear consistent for the two films.

The temperature and humidity test that most nearly approximated the flight conditions was a 84-day latent-image test of Type 104-01. During this test, the film was stored at 80°F at 50% RH. Test data showed a latent-image loss of 0.10 and 0.18 log exposure at the two densities evaluated. This is consistent with the flight results shown in Table 4-4b, although not directly comparable due to both environmental and time differences.

4.3 Performance Evaluation, Film Type SC-5

Kodak Special Film, Type SC-5, was used for Skylab Experiment S183 to study regions of the Milky Way that are dense in early-type stars in the ultraviolet spectral region. This film was produced on glass plates by Kodak Pathe Laboratories in France. Three carrousels of SC5 plates were launched during the Skylab missions. Carrousel 1-1, containing 36 SC-5 plates, were launched on SL1 in the Orbital Workshop, and was therefore exposed to temperatures as high as 125°F. Carrousel 1-2, which also contained 36 SC-5 plates, was launched on SL2 and was therefore exposed to only nominal spacecraft temperatures. Both carrousels were returned on SL2. Carrousel 1-1 was later launched on SL4 with six SC-5 plates but jammed due to a broken glass plate, so no scientific data were recorded. However, one SC-5 plate in this magazine was exposed with a step wedge image before launch. Therefore, storage data for this single plate were available.

4.3.1 Environmental Analysis Results, SC-5

Environmental timelines and SC-5 sensitometric curves representative of each S183 carrousel are given in Appendix D, Figures D-11 through D-13. Sensitometric exposures for this film were made at three different locations, as indicated on the curves. Exposures made at the Laboratoire d'Astronomie Spatiale (LAS), Marseilles, France, and those made at Marshall Space Flight Center (MSFC), were exposed with 260-nm radiation. Exposures made at Johnson Space Center (JSC) were exposed with visible light. Density measurements for this film were made at LAS with a Joyce Loeble microdensitometer using a 50- by 100-micrometer slit.

Analysis of the H & D curves indicates increases in base plus fog of 0.36 density units for both carrousels returned on SL2 and 0.22 density

units on the SL4 carrousel. Calculated estimates of the flight radiation dose for these carrousels were 1.49, 0.97, and 1.865 rads air for Carrousels 1-1 and 1-2 returned on SL2 and Carrousel 1-1 flown on SL4, respectively. Based on pre-mission test data, those dose levels were expected to yield base plus fog levels of 0.26, 0.18, and 0.31, respectively, as shown in Table 4-5. These data imply a strange coupling between radiation effects and storage time and temperature effects for the SL1/2 and SL2 film plates. The relatively low fog level on the SL4 plate is attributed to the severe latent image fading.

TABLE 4-5. ANALYSIS RESULTS, FILM TYPE SC-5

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
1-1 SL 1/2	+	1.491	0.26	.37
1-2 SL 2	+	.972	0.18	.35
1-1 SL4	+	1.865	0.31	.22

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT** TEST CONTROL-TEST PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1-1 SL 1/2	+	+	+	+	-0.12	-0.15	-1.97	-1.30
1-2 SL 2	-0.44	-0.77	+	+	-0.10	0.03	-0.99	-1.08
1-1 SL 4	-0.76	-0.94	+	+	-0.16	-0.16	-1.18	-1.32

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.3 ABOVE FOG	0.6 ABOVE FOG	0.3 ABOVE FOG	0.6 ABOVE FOG	0.3 ABOVE FOG	0.6 ABOVE FOG
1-1 SL 1/2	-.96	-1.41	+	+	+	+
1-2 SL 2	-.80	-1.60	+	+	+	+
1-1 SL 4	+	+	+	+	+	+

** Based on pre-mission test data using flight-data calculated dose.

* Based on pre-mission test data.

+ No data available.

Latent image fading of this film was considered to be severe. The fading caused a reduction in maximum density of more than 50% of the original density range. This effect, coupled with the increase in base plus fog, yielded a final film range for pre-mission exposures of 7, 28, and 42% of the original range for missions SL1/2, SL2, and SL4, respectively. The fading on the SL1/2 plate was so extensive that no data were available at densities of 0.3 and 0.6 above fog. The SL2 and SL4 data show a fading of from 1.5 to 3 f-stops.

Film sensitivity data also show a severe loss of sensitivity for the SL1/2 and SL2 carrousels. Comparison of FLIGHT POST DATA for plates launched on SL1 to data for plates launched on SL2 shows the loss of sensitivity to be about the same in spite of storage temperature and time differences. This loss was approximately equivalent to 3 f-stops at 0.3 above fog and 5 f-stops at 0.6 above fog.

When the SC-5 plates were developed after SL2, folds appeared on the emulsion after the film was placed in the developing solutions. This was caused by improper adhesion of the emulsion to the glass plate. However, this phenomenon did not occur on the SL4 plates. Therefore, the problem may have been induced by the higher temperatures experienced by the SL2 film. Mechanical constraints between the emulsion and its support that result from rehydration of the film after prolonged storage in vacuum were also identified as a potential cause of emulsion folding. These constraints can cause folding if the film is not rehydrated slowly before development and the emulsion is poorly attached to the glass plate.

4.3.2 Comparison of Flight and Test Data, SC-5

Flight and test data were compared for radiation effects and latent image effect. The comparison data, given in Table 4-5, indicate that the effect of storage time and temperature dominate over radiation effect. This makes comparison of the radiation effect inconclusive.

Pre-mission test of latent-image fading predicted approximately 30% more fading than was actually observed on the flight film. Due to the magnitude of image fading and the known batch-to-batch variation of this film, either data may be representatave of future film samples. However, latent image fading and sensitivity loss trends are considered definite.

4.4 Performance Evaluation, Film Type 101-05

Kodak Special Film, Type 101-05, a Schumann type emulsion for recording 5 to 400 nm radiation was used for Skylab Experiment S183 on

SL4. This film was selected as a replacement for SC-5 after the SL2 mission data showed severe environmental degradation of the SC-5 plates flown. Type 101-05 glass plates were procured and sent to France for loading in carrousels for the SL3 mission. First attempts at loading were unsuccessful due to plate fogging caused by an aluminum tool used for loading. Therefore, new plates were loaded by hand the the flight carrousels were hand carried to Kennedy Space Center (KSC). Upon arrival, it was discovered that the plates were again fogged. The cause of this fogging, although believed to be a chemical reaction with outgassed material from the carrousel, could not be isolated. Therefore, no 101-05 or SC-5 film was flown on SL3.

During the SL3 mission, the carrousels were cleaned, baked, and tested with 101-05 plates. In preparation for the SL4 mission, ten 101-05 plates were manually loaded in Carrousel 1-1 along with 19 103a-0 plates, six SC-5 plates, and one 101-06 plate. However, a SC-5 plate was mounted defectively, and broke. This led to a mechanical failure of the spectrophotometric camera that caused desynchronization of the magazine and no flight exposures could be taken.

4.4.1 Environmental Analysis Results, 101-05

One 101-05 plate launched on SL4 had a pre-mission sensitometric exposure to 260-nm radiation at LAS, and one plate was exposed at JSC after the mission. Due to both sensitometer and densitometer difference between LAS and JSC, these data are plotted separately, with corresponding controls and test data, in Appendix D, Figure D-14. The curves show a large increase in base plus fog, and a significant decrease in maximum density. This resulted in a reduction of the flight film density range to less than 0.4 density units for both pre-flight and post-flight sensitometry. This is less than 28% of the original range.

Because of the small data sample, the radiation data analysis for this film was inconclusive. Applying the flight-data calculated radiation dose to the pre-mission test data implies that more than 60% of the base-plus fog increase was due to storage time and temperature, and the radiation effects were minor by comparison.

The reduction in density range made it impossible to analyze latent image and film sensitivity at densities of 0.6 and 1.2 above fog. Therefore, these data were reduced for 0.2 and 0.3 density units above fog. The data are given in Table 4-6, and show a latent image fading in excess of 3.5 f-stops at density 0.2 above fog and 5.4 f-stops at 0.3 above fog. On the other hand, the postflight data show a loss of sensitivity of only 0.3 and 1.3 f-stops, respectively.

TABLE 4-6. ANALYSIS RESULTS, FILM TYPE 101-05

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
1-1	+	1.865	0.3 + radiation fog	0.5

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		FOGGING EFFECT TEST PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.2 ABOVE FOG	0.3 ABOVE FOG	0.2 ABOVE FOG	0.3 ABOVE FOG	0.2 ABOVE FOG	0.3 ABOVE FOG	0.2 ABOVE FOG	0.3 ABOVE FOG
1-1	-1.07	-1.63	-0.62	-0.77	-0.45	-0.66	0.04*	0.01*

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.2 ABOVE FOG	0.3 ABOVE FOG	0.2 ABOVE FOG	0.3 ABOVE FOG	0.2 ABOVE FOG	0.3 ABOVE FOG
1-1	-0.09	-0.40	+	+	+	+

+ No data available.

* Based on pre-mission 12-week simulation in Carrousel 2-1, Position 27.

4.4.2 Comparison of Flight and Test Data, 101-05

Test data available for comparative analysis were the 12-week simulation conducted for latent-image effects with Carrousel 2-1 during the SL3 mission. However, these data do not compare well with the flight data, indicating an apparent difference in the two carrousels. Environmental

problems encountered with this film indicate a need for more detailed understanding of how to store and use thse Schumann-type emulsion films in space applications. This is particularly important because the atmosphere is opaque in the spectral region for which these films are used and precludes their use in terrestrial telescopes. Therefore, future use of these materials in space is likely.

4.5 Performance Evaluation, Film Type 101-06

Kodak Special Film, Type 101-06, is a high speec (approximately 10 time faster than 104-06) Schumann-type emulsion for recording 5 to 400 nm radiation. It is the same emulsion as 101-05 but is coated on 7 mil ESTAR base with beaded edges.

Type 101-06 was used on Skylab Experiments S019 (UV Stellar Astronomy), S020 (X-Ray/UV Solar Photography), S082A (Extremely Ultraviolet Spectroheliograph), and S082B (Spectrograph and Extreme Ultraviolet Monitor). Experiment S019 photographed stellar UV emission and absorption spectra in 130 to 500 nm wavelengths, S020 photographed X-Ray/UV solar line spectra in 1 to 20 nm wavelengths, S082A photographs Solar Chromosphere and corona in the XUV wavelengths between 15 and 62.5 nm and S082B photographed line spectra of small selected areas on and off the solar disk and across the limb in two wavelength bands; 97 to 197 nm or 194 to 394 nm.

Experiment S019 used 164 individual slides in each film canister. One canister was used during SL2 and two each during SL3 and SL4. The principal investigator, Dr. K. Henize, reported that hundreds of stellar spectra were successfully recorded. Each film slide was mounted to a stainless steel plate with a grid of lightening holes. A very noticeable fogging pattern, corresponding to the stainless steel plate configuration, was present on most slides, except in areas covered by a nylon retaining frame. The cause of the fogging could not be isolated but was assumed to be associated with proximity to stainless steel. The course of the fog is still unresolved. The fogging did not, in general, degrade the quality of the spectra for accurate spectrophotometry.

Experiment S020 used 10 strips of 101-06 film in each magazine. Experiment operations were originally scheduled to use the solar Scientific Airlock on all missions but were limited to operating only during extravehicular activity because the airlock was used for the parasol. During SL4, eight exposures were obtained during three of the four extravehicular activities. The principal investigator, Dr. R. Tousey, reported that good solar spectra were obtained. No sensitometry data were, however, recorded on this film. The Naval Research Laboratory reported the film to vary from batch to batch. Aging characteristics were also unpredictable. The batch used for the flight film was received in April 1973. It was not

possible to procure fresher film. When loaded in October, 1973, no degradation had occurred. Analysis of the returned flight film, the background density was higher than expected, and a modulation effect in the film, resembling a picket fence, was observed along the length of the film. The modulation effect was oriented 5 to 10 degrees from the direction of the spectral lines and was therefore removable by proper processing. This picket fence pattern was also present in the ground control films, but to a lesser degree. Both ground control and flight films had a base plus fog level of about 0.5 density units; the predicted fog increase of 0.5 from proton fogging was not observed.

Experiment S082A and S082B used individual 101-06 film strips mounted in the SL2 carrousels to determine if this film would degrade too severely for use on Skylab. These test strips gave satisfactory results, so ten 101-06 film strips were included in S082A and 50 in S082B SL4 canisters. The principal investigator, Dr. R. Tousey, reported good results with this film. Sensitometry data was obtained for only one film strip from S082B that was exposed during SL4. This film strip showed some evidence of light leakage and grain enlargement that was not observed in the 104-06 film. This film strip also confirmed that proton radiation was not a problem.

Testing of Schumann type films by the Naval Research Laboratory has been limited to pressures greater than 10^{-5} Torr. It was recommended that testing at lower pressures (10^{-6} to 10^{-12} Torr) be conducted to determine what specific changes occur.

4.5.1 Environmental Analysis Results, 101-06

Sensitometric data for environmental analysis of this type of film was limited to a single flight H & D curve and environmental timeline for carrousel B-4 on the S082B experiment. Both this curve and the REPRESENTATIVE CONTROL given in Appendix D, Figure D-15, were generated from film exposed to radiation at 175-nm wavelength. These data were defined as representative of that film and carrousel.

Evaluation of the H & D curves shows an increase in base plug fog of less than 0.02 density units. The calculated radiation dose for this carrousel was 1.17 rads air. This demonstrates that this film was relatively insensitive to the space ionizing radiation. Analytical results are given in Table 4-7.

TABLE 4-7. ANALYSIS RESULTS, FILM TYPE 101-06

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, CO^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
B-4	+	1.17	+	0.02

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
B-4	-0.21	-0.66	+	+	+	+	+	+

Evaluation of image stability showed a reduction in the maximum density similar to that observed for film type 104-06. This resulted in a reduction of film response (See Table 4-7b) equivalent to approximately 2/3 f stop at 0.6 above fog and 2 f stops at 1.2 above fog. This effect could not be separated into contributions due to latent image fading and loss of film sensitivity since the date of exposure for the flight data was not available.

No test data were available for comparative analysis.

4.6 Performance Evaluation, Film Type 103a-0

Film 103a-0 was primarily used in 16-mm format on Experiment S183 with a Maurer camera operating at 250 nm. Nineteen 103a-0 glass plates were flown in Carrousel 1-1 on SL4, but no scientific data were recorded due to a broken plate that caused magazine failure. However, environmental storage data were available on one 103a-0 plate. Adequate data were available to evaluate the environmental effects on three of the four 16-mm rolls flown. There were some operational problems with the Maurer cameras

that effected the scientific data, but no film-related anomalies were defined. The 103a-0 was considered adequate to meet experiment scientific requirements.

4.6.1 Environmental Analysis Results, 103a-0

The H & D curves and related film-roll timelines for this type of film are given in Appendix D, Figure D-16 through D-19. Note that the densities for Rolls UA01, UA02, and UA03 were measured at JSC using a MacBeth TD504 diffuse densitometer with a 3-mm aperature. The densities the glass plates illustrated for Carrousel 1-1 on SL4 were measured at LAS, France, with a Joyce Loebl microdensitometer, using a 50- x 100-micrometer slit. Therefore, these data are not directly comparable.

Numerical analysis data given in Table 4-8 show that flight film fogging for the 16-mm rolls did not track the flight-data calculated dose. The 0.42 density difference in fog level between UA01, launched on SL1, and UA03, launched on SL2, indicates a large increase in fog due to the high SL1 temperatures. On the other hand, fog on rolls UA02 and UA03, appears to show comparatively little temperature effect. The cause of the higher-than-expected fogging on the Carrousel 1-1 plate is not known. However, it may be representative of 103a-0 glass plates.

Latent-image-effect data support the fogging data and show a considerable effect due fogging, resulting in an overall latent-image loss of approximately 4/5 of an f-stop. JSC control data show that storage at room temperature resulted in a small image growth for UA01 and UA03 storage periods (SL 1/2), and a small image loss for the UA02 period (SL3). However, caution should be used in applying the temperature/humidity effects data for UA01 because of the difference in the flight-film temperature and JSC control-film temperature.

Film sensitivity data show an unusual effect in that the higher temperatures of SL1 and SL2 appeared to retard a loss of sensitivity observed in the SL3 film. This can be identified from the data shown in Table 4-8c, in which the temperature/humidity effects oppose the radiation or fogging effects for rolls UA01 and UA03 and add for Roll UA02. In addition, the loss of sensitivity due to radiation or fogging effects was much larger for UA02. This resulted in a net sensitivity loss that was negligible for UA01, almost 1 f-stop for UA02, and a slight increase in sensitivity (1/4 f-stop) for UA03.

TABLE 4-8. ANALYSIS RESULTS, FILM TYPE 103a-0

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
UA01	+	0.912	0.27**	0.64
UA02	1.412	1.493	0.41	0.37
UA03	+	0.910	0.27**	0.22
1-1	+	1.865	0.50**	1.00

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		FOGGING EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
UA01	-0.14	-0.20	0.07	0.08	-0.21	-0.28	+	+
UA02	-0.27	-0.24	-0.06	-0.02	-0.21	-0.22	+	+
UA03	+	+	0.08	0.09	+	+	+	+
1-1	-0.14	-0.18	+	+	+	+	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
UA01	-0.02	-0.06	0.07	0.08	-0.09	-0.14
UA02	-0.26	-0.28	-0.06	-0.02	-0.20	-0.26
UA03	0.06	0.07	0.08	0.09	-0.02	-0.02
1-1	+	+	+	+	+	+

+ No data available.

** Based on pre-mission test data using flight-data calculated dose.

4.7 Performance Evaluation, Film Type SO-101

Kodak Solar Flare Patrol Film, Type SO-101, was used to take high-resolution H-alpha photographs of the solar disk and thus provide permanent records of ATM pointing. This film had an extremely slow speed

and was therefore virtually insensitive to Skylab environments. Five rolls (35 mm x 1000 ft) were flown, but environmental effects data were available for only three rolls at the time of this study. Users of Skylab H-alpha film data identified no film-associated problems or anomalies. They also described this film as well suited to this application and adequate for the telescope and data reduction requirements.

4.7.1 Environmental Analysis Results, SO-101

Sensitometric data for this film type were limited to "Flight Pre" and "Ground Control" imagery. Therefore, film sensitivity effects could not be analyzed. Environmental timelines and H & D curves from these exposures are given in Appendix D, Figures D-20 through D-22. Numerical analysis results of these data are given in Table 4-9.

TABLE 4-9. ANALYSIS RESULTS, FILM TYPE SO-101

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
2	+	2.38	0.01*	0.06
3	+	2.38	0.01*	0.03
4	+	4.72	0.02*	0.09

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
2	-0.02	-0.03	+	+	+	+	+	+
3	-0.09	-0.06	+	+	+	+	+	+
4	-0.02	-0.03	+	+	+	+	+	+

+ No data available.
* Based on test data using flight data calculated dose.

Although the increase in base plus fog was small for all three rolls analyzed, it was significantly higher than the fog projected by pre-mission test results using the flight-data calculated dose (see Table 4-9a). The cause of this difference is not certain but is expected to be the long storage periods and temperatures experienced by these film rolls. This slight increase in base plus fog also appeared to be the cause of the small latent image losses shown in Table 4-9b. However, these changes in film response are within processing error and are negligable for film data applications.

4.8 Performance Evaluation, Film Type 3414

Type 3414, High Definition Aerial Film, was used during the Skylab mission on the Earth Resources Experiment Package Experiment S190B, Earth Terrain Camera. One roll 5 in. (12.7 cm) wide by 210 ft (64 m) long was used on each of the three manned missions. One roll of 35-mm Type 3414 was launched on SL2 but was not used nor returned due to inaccessibility of the solar scientific airlock. Type 3414 film is a very high-resolution fine-grained film, and therefore has a very slow speed. Consequently, it was comparatively insensitive to Skylab environments that caused degradation of faster, more sensitive films. Evaluation of the flight imagery and sensitometry showed no film anomalies. Imagery produced was of very high quality and yielded ground resolution on the order of ten meters under ideal atmospheric conditions.

4.8.1 Environmental Analysis Results, 3414

H & D curves for the analysis of this film are given in Appendix D Figures D-23 through D-25. Numerical analysis data are given in Table 4-10. These data show no measurable increase in base plus fog, and all changes in film response were so small that they were within the variance expected for film processing.

The base plus fog level observed for the "Houston Pre" and "Houston Post" on Roll 82 was lower than both the flight and control films. This minor difference did not affect data analysis results.

Latent image effects data show a very slight latent image loss ($< \frac{1}{4}$ f-stop) for all three rolls at both 0.6 and 1.2 density above fog. This fading was entirely due to storage time, temperature, and humidity. No effects of ionizing radiation were observed.

A very slight decrease in film sensitivity ($\sim \frac{1}{4}$ f stop) is observable at a density of 1.2 above fog for all three rolls but only on Roll 89 at a density of 0.6 above fog. Again, the trend is toward no radiation effect, however, the data show both small opposing and additive effects of

TABLE 4-10. ANALYSIS RESULTS, FILM TYPE 3414

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
82	0.89	0.65	< 0.01	< 0.01
85	1.34	1.05	0.036	< 0.01
89	+	1.47	+	< 0.01

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
82	-0.04	-0.08	-0.02	-0.08	-0.06	0	+	+
85	-0.04	-0.08	-0.04	-0.08	0	0	+	+
89	-0.03	-0.04	-0.03	-0.04	0	0	+	+
Average	-0.037	-0.067	-0.03	-0.067	-0.02	0	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
82	0	-0.08	-0.04	-0.04	0.04	-0.04
85	0	-0.08	0	-0.04	0	-0.04
89	-0.06	-0.07	-0.06	-0.07	0	0
Average	-0.02	-0.077	-0.033	-0.05	0.013	-0.027

temperature and humidity versus radiation for Rolls 82 and 85. All environmental effects on this film were so small they could be neglected except for radiometric applications.

4.8.2 Comparison of Flight and Test Data, 3414

Test data available for this film were limited to ionizing radiation. These data show that flight film base plus fog was less than 0.01 density units for all three rolls. Pre-mission raw test data also showed less than 0.01 density fogging. However, the pre-mission prediction shown in Table 4-10 predicts fogging of 0.036 for Roll 85. It was therefore, concluded that the predicted value was in error and the actual test and flight data are in good agreement.

4.9 Performance Evaluation, Film Type 3400

Kodak PANATOMIC-X Aerial Film, Type 3400 was a candidate for several Skylab experiments prior to the Skylab mission and was tested extensively during pre-mission tests. Modifications of this film were desired based on the special requirements of several Skylab experiments. To satisfy these requirements and other applications outside the Skylab Program, Kodak provided three film types (SO-212, SO-022 and 026-02) for Skylab experiments that were derived from film type 3400. The special characteristics of these films are described in Appendix A. Performance evaluations of these films are presented in paragraphs 4.10, 4.11 and 4.12 respectively.

Two rolls of type 3400 film (35 mm x 9 ft) were launched on SL4 in support of experiment T025, Coronagraph Contamination Measurement. However, these rolls were not used to record in-flight data and, consequently, were not returned from space. Therefore, no flight data was available to evaluate the Skylab environmental effects on this film type.

4.10 Performance Evaluation, Film Type SO-212

Kodak Spectroscopic XUV Film, Type SO-212, was used in two Skylab, ATM Experiments; S054 X-Ray Spectrographic Telescope and S056 X-ray Telescope. These telescopes recorded solar images in 0.3 to 6 nm (3 to 60 Å) and 0.5 to 3.3 nm (5 to 33 Å) spectral bands respectively. Radiation at several wavelengths within these spectral bands is strongly absorbed by the gelatine overcoat on photographic film. This radiation is also absorbed by air, requiring these telescopes and the data recording cameras to operate above the earth's atmosphere in an evacuated condition. These considerations led to the development of film type SO-212 which is the production version of 3400 emulsion with no gelatine overcoat to attenuate the radiation and a Rem Jet anti-static backing to minimize electrostatic images resulting from vacuum operation.

The X-Ray Spectrographic Telescope, S054, used five 70 mm by 1300 ft (400 meter) rolls of SO-212. These were designed as filmloads A through

E. Filmloads A through D were launched on SL1 and filmload E on SL4. Filmload A was used and returned on SL2, filmloads B and C on SL3 and filmloads D and E on SL4. Evaluation of the S054 scientific data showed this film fulfilled the experiment requirements very well and no film anomalies were identified. This evaluation did, however, show the brightness range of the sun in the soft X-ray spectral region to be extremely wide and beyond the dynamic range of the film. Therefore, it was recommended that future experiments use a lower film gamma to better record this wide brightness range. The gamma of the film used on this experiment was 1.39 ± 0.05. S054 investigators also identified a need for additional data on latent image fading and maintenance of film sensitivity during storage for extended periods at low temperatures.

The X-Ray Telescope, S056, used four rolls of SO-212 and one roll of SO-242, each 35 mm by 1000 ft. The SO-242 roll, designated as load 5, is discussed in paragraph 4.18. Rolls 1 through 4 were launched on SL1 and returned as follows: load 1 on SL2, loads 2 and 3 on SL3 and load 4 on SL4. S056 Principal Investigators described the photographic capability of SO-212 as adequate for this application but noted the same dynamic range and high gamma difficulty as the S054 experiment personnel. This made the data particularly hard to copy. They also indicated that the resolution of the telescope was limited by the photographic film; and higher resolution was obtained with the SO-242 color film. However, lower detection quantum efficiency of SO-242 caused an undesirable loss of low intensity data. No photographic anomalies were identified on the SO-212 film but small abrasions due to the film backing rubbing on the emulsion surface during winding were prevalent. A need for more research on the application of photographic film in the soft X-ray spectral region was identified, particularly in the areas of: film sensitivity as a function of wavelength, film calibration and sensitometry, film processing versus application and development of a soft X-ray sensitometer.

4.10.1 Environmental Analysis Results, SO-212

Sensitometric data for environmental analysis was available for S054 filmloads A, B and D and all four S056 loads. Environmental timelines and H & D curves for these film loads are plotted in Appendix D, Figures D-26 through D-32. S054 sensitometry was exposed with soft X-ray radiation at 0.83 nm (8.3 Å) and 4.4 nm (44 Å, filmload B only); while S056 sensitometry was exposed using visible light. Sensitometry data for S054 was, however, limited to FLIGHT PRE and GROUND CONTROL because of the long time required to make sensitometric exposures at these soft X-ray wavelengths. Analytical results are given in Table 4-11.

TABLE 4-11. ANALYSIS RESULTS, FILM TYPE SO-212

a. RADIATION DATA COMPARISON

ROLL NUMBER		PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	TEST DATA PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
A	S054	+	0.78	0.04	0.03
B	S054	+	2.44	0.13	0.11
C	S054	+	+	+	0.11
D	S054	+	3.64	0.20	0.22
E	S054	+	+	+	0.08
Load 1	S056	+	1.00	0.05	0.06
Load 2	S056	+	2.29	0.12	0.13
Load 3	S056	+	2.45	0.13	0.16
Load 4	S056	+	2.99	0.16	0.24

b. LATENT IMAGE EFFECTS

ROLL NUMBER		DELTA LOG EXPOSURE							
		FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		FLIGHT ENVIRONMENT EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
		0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
A	0.83 nm	-0.04	-0.06	+	+	+	+	+	+
B	0.83 nm	-0.04	0						
D	0.83 nm	-0.02	-0.07						
B	4.4 nm	-0.01	-0.04	+	+	+	+	+	+
Load 1	Visible	-0.13	-0.15	-0.23	-0.27	-0.10	-0.12	-0.14	-0.16
Load 2	Visible	-0.11	-0.14	-0.06	-0.04	-0.05	-0.10		
Load 3	Visible	-0.16	-0.10	-0.12	-0.06	-0.04	-0.04		
Load 4	Visible	-0.16	-0.22	-0.12	-0.12	-0.04	-0.10		

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER		DELTA LOG EXPOSURE					
		FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
		0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
Load 1	Visible	0.12	0.08	0.11	0.04	0.01	0.04
Load 2	Visible	0.02	-0.05	0.06	0.04	-0.04	-0.09
Load 3	Visible	-0.07	-0.07	-0.04	-0.01	-0.03	-0.06
Load 4	Visible	-0.06	-0.09	-0.03	-0.06	-0.03	-0.04

*Based On Pre-Mission Test Data, 84 Days at $80^{\circ}F$ and 50% R.H.

The fog levels measured, see Table 4-11a, from the flight films were in excellent agreement with the test values derived using flight calculated doses for all rolls except S056 load 4. The cause of higher fog on this roll could not be isolated.

The latent image fading data, given in Table 4-11b, show a definite difference in the latent image fading of the soft X-ray images and the visible light images. X-Ray images shown average fading of ~1/8 f stop while the visible light images shown average image fading of ~1/2 f stop. This showed that latent image fading of X-ray imagery was small compared to visible imagery. Therefore, visible sensitometry data cannot be used to predict environmental effects on soft X-ray exposures.

Visible light data for S056, load 1 showed a comparatively large, latent image effect (almost one f stop) on the HOUSTON PRE film stored at ambient room conditions at ~ 50% RH. The FLIGHT PRE, which was stored mostly in a vacuum but also near room temperature, showed much less fading. This illustrates that the removal of water vapor and oxygen retarded latent image fading. This phenomenon was also observed during pre-mission environmental testing. The remainder of the S056 rolls showed consistent latent image fading of ~1/2 f stop. A separation of image fading into environmental components could not be done because of the variance in flight environments between film loads. However, flight data did show good correlation with the pre-mission temperature/humidity test data.

Film sensitivity data were available for only the S056 visible light exposures. These data showed a small increase in sensitivity for load 1 with a trend toward decreasing sensitivity for longer storage times.

4.11 Performance Evaluation, Film Type SO-022

Kodak PANATOMIC-X Aerial Film, Type SO-022, was used in the Multispectral Photographic Camera, Experiment S190A. The camera had six camera stations, each imaging in a separate spectral band, with separate 70-mm 110-ft film rolls. Film type SO-022 was used in camera stations 5 and 6, which recorded imagery of the Earth's surface in the spectral bands of 600 to 700 nm and 500 to 600 nm, respectively.

The Multispectral Photographic Camera was especially designed to produce radiometrically accurate photographic imagery. Therefore, each roll of film was provided with both broadband and spectral sensitometric images before and after each mission. The broadband sensitometric images were recorded with Wratten 57 and 25A filters in the sensitometer light path to simulate the operational spectrum of each camera station. Reduction of these broadband sensitometric images was the basis for the environmental effects analysis.

Thirty-two cassettes of SO-022 film were launched for use on Skylab. Six cassettes were launched on SL1 and 5/14/73, stowed in the OWS film vault. Due to anomalous environmental conditions occurring on SL1 before SL2 launch, two new cassettes were launched on SL2 on 5/24/73 to replace film possibly damaged during the orbital storage period. Four cassettes of SO-022 from the SL1 film launch were used for on-orbit photography as well as the two resupplied on SL2. Camera stations, magazine numbers, and mission launch for all SO-022 film used during Skylab are listed below.

Camera Station	Film Roll Number	Launch
5	05	SL2
5	11, 17	SL1
6	06	SL2
6	12, 18	SL1
5	23, 29, 35, 41, 47	SL3
6	24, 30, 36, 42, 48	SL3
5	53*, 59, 65, 71, 77, A5, B5	SL4
6	54*, 60, 66, 72, 78, A6, B6	SL4

Due to a procedural error, filters were inadvertently not installed on the camera for EREP passes 53 through 62. Therefore, film rolls marked with an asterisk were exposed without filters and provided broad-band panchromatic imagery limited only by the spectral sensitivity of the film. Under these conditions, data from camera stations 5 and 6 were identical. Therefore, Roll 54 was not processed and Roll 53 required special processing to compensate for the overexposure caused by omission of the filter.

4.11.1 Environmental Analysis Results, SO-022

Environmental timelines and H & D curves on which the SO-022 analysis was based are presented in Appendix D, Figure D-33 through D-44. As illustrated by these curves, environmental degradation effects on this film type were minimal. Table 4-12a shows that the increase in base plus fog varied from 0.02 density units on a film roll launched on SL2 to 0.07 density units for the film receiving the maximum radiation dose on SL4.

Detailed analysis of the shift in the H & D curves resulting from latent image fading shows a range from no latent image fading on Roll 05 to an image loss of 0.16 and 0.15 log exposure at densities 0.6 and 1.2 above fog, respectively, for Roll B5. A loss of 0.15 log exposure is equivalent to 1/2 f-stop. Note in Table 4-12b that for Roll 05 the

TABLE 4-12 ANALYSIS RESULTS, FILM TYPE SO-022

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
5	0.66	0.47	0.02	0.03
6	0.66	0.47	0.02	0.02
17	0.76	0.65	0.02	0.04
18	0.76	0.65	0.02	0.04
23	1.22	1.00	0.04	0.06
24	1.22	1.00	0.04	0.05
47	1.19	0.94	0.04	0.06
48	1.19	0.94	0.04	0.06
59	+	1.55	+	0.07
60	+	1.55	+	0.06
B5	+	1.91	+	0.07
B6	+	1.91	+	0.07

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
5	0	0	0.04	0.05	-0.04	-0.05	-0.12	-0.15
17	-0.09	-0.06	-0.12	-0.05	0.03	0.03	-0.10	-0.15
23	-0.08	-0.11	-0.07	-0.07	-0.01	-0.04	-0.05	-0.17
47	-0.08	-0.07	-0.09	-0.09	-0.01	-0.02	-0.05	-0.17
59	-0.09	-0.11	-0.10	-0.11	0.01	0	-0.17	-0.19
B5	-0.16	-0.15	-0.12	-0.11	-0.04	-0.06	-0.17	-0.19
Average	-0.083	-0.083	-0.077	-0.063	-0.01	-0.023	-0.11	-0.17
6	-0.10	-0.08	-0.10	-0.06	0	-0.02	-0.12	-0.15
18	0.02	0.04	-0.01	0.03	0.03	0.01	-0.10	-0.15
24	0	0.01	0.02	0.03	-0.02	-0.02	-0.05	-0.17
48	-0.03	-0.01	0	0	-0.03	-0.01	-0.05	-0.17
60	-0.04	-0.01	0.01	-0.01	-0.05	0	-0.17	-0.17
B6	-0.03	-0.04	0	-0.04	-0.03	0	-0.17	-0.19
Average	-0.015	-0.015	-0.013	-0.008	-0.16	-0.003	-0.11	-0.17

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
5	0.10	0.10	0.14	0.13	-0.04	-0.03
17	0.08	0.13	0	0	0.08	0.13
23	0.01	0.02	0	0.02	0.01	0
47	0.02	0.02	-0.03	0	0.05	0.02
59	0.04	0.04	0.04	0.03	0	0.01
B5	-0.03	-0.03	0	0	-0.03	-0.03
Average	0.037	0.047	0.025	0.03	0.012	0.017
6	0.02	0.01	0	0	0.02	0.01
18	0.07	0.13	0.10	0.15	0.07	-0.02
24	0.11	0.11	-0.01	-0.04	0.12	0.15
48	0.09	0.09	0.08	0.08	0.01	0.01
60	0.10	0.09	0.09	0.08	0.01	0.01
B6	0.05	0.03	0.05	0.05	0	-0.02
Average	0.073	0.077	0.052	0.053	0.038	0.023

+ No data available.

* Based on pre-mission test data.

effects of temperature/humidity and ionizing radiation were equal in magnitude but opposite in direction. This resulted in no change in film response at the density levels above fog evaluated for the pre-mission exposure. However, this cancellation of effects is exceptional. Ratioing the average effects of temperature/humidity and radiation separately with the resultant effect on the flight film shows that, at a density of 0.6 above fog, ~90% of latent image fading was due to the effect of storage time, temperature, and humidity, and 10% due to radiation. At 1.6 density units above fog, ~75% of the fading was due to time, temperature, and humidity, and 25% due to radiation.

Analysis of the post-mission sensitometric curves is summarized in Table 4-12c. These results show a slight increase in sensitivity (0.01 to 0.13 log E) for all rolls except B5. Average calculations show that, at both density values evaluated, ~65 to 70% of the sensitivity change was due to time, temperature, and humidity, and ~30% was caused by ionizing radiation effects.

4.11.2 Comparison of Flight and Test Data, SO-022

Pre-mission comparative test data were available only for ionizing radiation effect and latent image fading effects. The ionizing radiation comparison is given in Table 4-12a. For this film type, the pre-mission dose prediction was approximately 12% higher than the flight-data calculated dose. On the other hand, the predicted increase in base plus fog, was ~30% less than the actual fog increase. However, this apparent variance is expected because the actual base plus fog also includes time, temperature, and humidity effects. Therefore, test and flight radiation effects data are considered to be in very good agreement.

Comparison of latent-image-effect data is much more difficult because pre-mission test data were limited to temperatures of 80, 100 and 120°F. Therefore, the lowest test temperature was ~10° higher than the nominal Skylab temperature. Comparative data listed in Table 4-12b are consistent with this temperature difference. As can be observed, the average density for the test data is 0.02 to 0.087 log exposure higher than that for the flight data. This appears to be a valid expected difference for the difference in temperature, and adds credibility to the test data.

4.12 Performance Evaluation, Film Type 026-02

Kodak Special Film, Type 026-02 was used on the White Light Coronagraph, Experiment S052. Five film loads were flown on Skylab. Each load consisted of a hermetically sealed film camera containing 750 ft (228 meters) of35 mm 026-02 thin base film. Each camera was pressurized to

5.2 psia with 45-percent relative humidity gaseous nitrogen. Film load 1 was launched in the Coronagraph and loads 2, 3 and 4 in MDA film vaults on SL1. Film load 5 was launched on SL4 in the Command Module. One film load was used on SL2 and two each of SL3 and SL4.

Film type 026-02 was a derivative of film type 3400 modified specifically for the S052 experiment. The film performed very well in this application and fulfilled the experiment requirements adequately. The film, as supplied by the manufacture, was found to have a few (approximately 8 to 10 per roll) plus density streaks running diagonally across the film. These streaks were attributed to manufacturing but were infrequent and affected only a very small percentage of the data. The film also had more particulate matter on it than expected. Therefore, visual examination and selective destructive testing was employed to selected optimum rolls for flight.

Reticulation was observed on the processed 026-02 film. This phenomenon, which is a series of ridges and valleys in the surface of the photographic film, was caused by swelling and subsequent contraction of the film gelatin during processing. This condition was corrected by replacing the distilled water wash bath following development with Kodak stop bath SB5. Detailed discussion of this anomaly are given in reference 4p.

4.12.1 Environmental Analysis Results, 026-02

Sensitometric data for environmental effects evaluatio provided from two types of calibration wedges. These included calib n wedges applied with a specially designed sensitometer box (reference 4u) on the front end of each flight roll at the time of camera loading and a calibration wedge applied to each frame of scientific data at the time of data recording with an inflight calibration system. The latter system used the sun as the exposing light source. H & D curves were plotted from the inflight wedges for the first and last frames of rolls 2 through 5. These curves and the complimentary environmental timelines are given in Appendix D, Figures D-45 through D-48. Individual curves are designated as FLIGHT HEAD and FLIGHT TAIL identifying the first and last frames respectively. These curves are summarized in figure 4-3a and 4-3b to show roll to roll variations. Figure 4-3c gives a summary of the available data from the ground based sensitometer. Curves for loads one and five are not shown because there was some uncertainty in the sensitometry in those cases (reference 4o).

Table 4-13 gives analysis results derived from the H & D curves and data reported in reference 4o. The radiation data (Table 4-13a) show the pre-mission Dose Prediction was 80 to 100% higher than the Flight Calculated

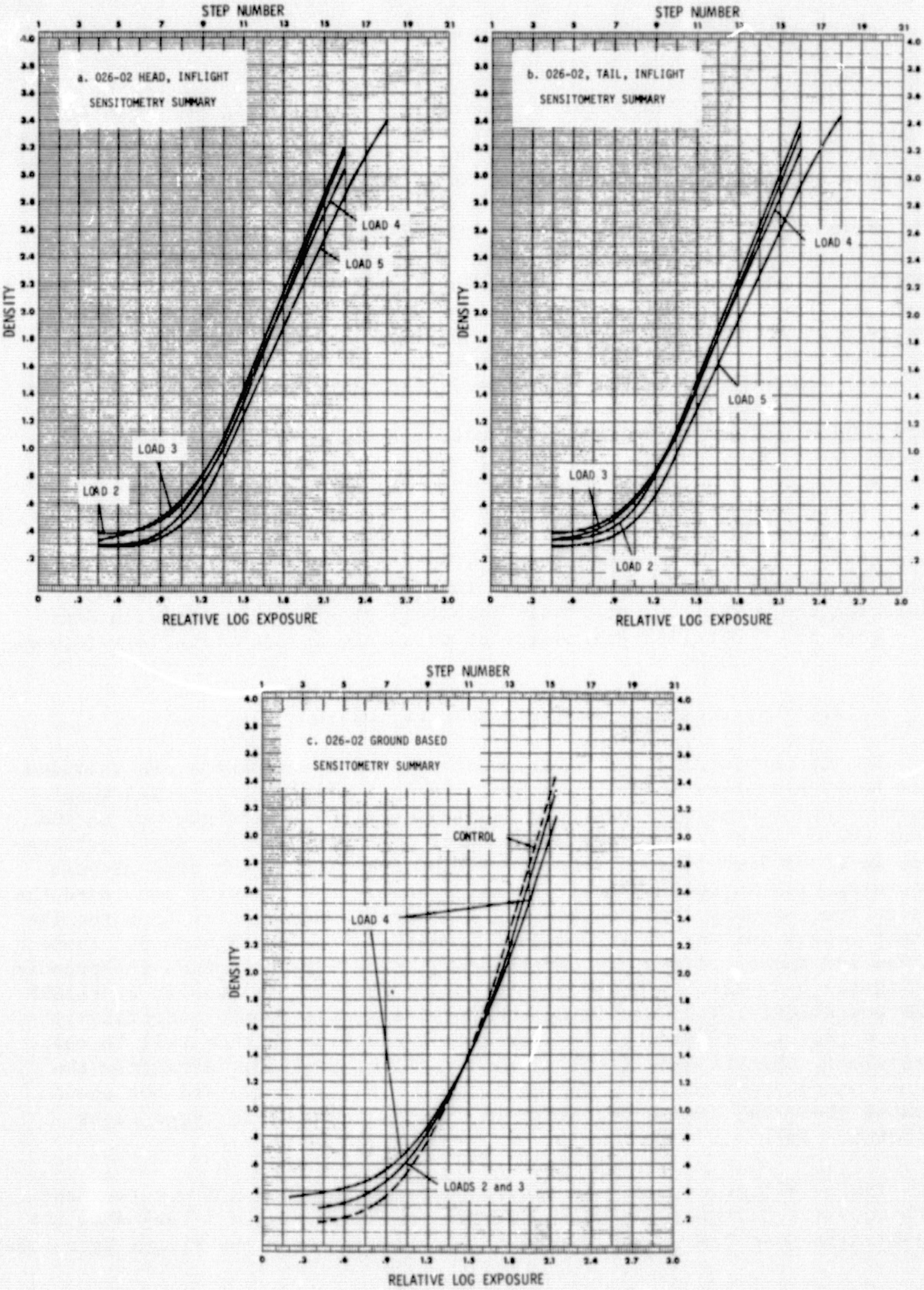


FIGURE 4-3. SENSITOMETRY SUMMARY, FILM TYPE 026-02

TABLE 4-13. ANALYSIS RESULTS, FILM TYPE 026-02

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)		ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
1	2.1	1.09	0.06	(0.03)*	0.01
2	4.5	2.99	0.16	(0.09)*	0.10
3	4.5	2.59	0.16	(0.07)*	0.10
4	8.5	4.38	0.31	(0.16)*	0.21
5	3.4	2.05	0.11	(0.06)*	0.01

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA GROUND SENSITOMETER CONTROL-FLIGHT PRE AT DENSITY:		FLIGHT FILM DATA INFLIGHT SENSITOMETER FLIGHT TAIL-FLIGHT HEAD AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	2.8 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1	+	+	+	+	+	+	-0.10	-0.13
2	-0.03	-0.08	-0.02	-0.04	+	+	-0.14	-0.19
3	-0.03	-0.08	0.03	-0.04	+	+	-0.13	-0.18
4	-0.08	-0.19	-0.03	-0.03	+	+	-0.15	-0.22
5	+	+	-0.03	-0.03	+	+	-0.14	-0.17

*Based on pre-mission test data using flight data calculated dose.

+ No data available.

Dose. This result is consistent with the difference between the pre-mission predicted and actual increase in base plus fog. Therefore, base plus fog values on the flight film were much less than expected. These results show that radiation fog was not a serious problem and the increase in fog caused only a slight decrease in the effective film sensitivity.

Latent image effect data (Table 4-13b) show a variance in the trends between the ground based and inflight sensitometry. The ground based sensitometer data shows the latent image fading increasing with storage time and film density. The inflight sensitometry, on the other hand, showed a small constant effect regardless of storage time or density. Based on trends established during pre-mission testing and on a larger

than expected scatter of the inflight sensitometry data points, a higher confidence was placed on the ground based sensitometry data. These data showed that latent image effects were for this film small and could be neglected in all applications except absolute radiometry.

4.12.2 Comparison of Flight and Test Data, 026-02

Comparison of the flight and test radiation base plus fog data required that base plus fog values predicted by the test data for the flight data calculated dose be determined. These values, shown in parenthesis in Table 4-13a, compare fairly well with the actual increase in fog with the exception of load 5. Some error was expected due to the potential inaccuracy (up to a factor of 2) of the Flight-Data Calculated Dose. However, the close comparison of fog levels for most of the film loads show the Flight Data Calculated Dose generally had good accuracy.

Latent image pre-mission test data were available for periods up to 252 days. These data simulated the 50% relative humidity in gaseous nitrogen at temperatures of 40, 70, 80 and 90°F. Short term exposures to air were present in the simulation due to a requirement to remove test data from environmental test chambers approximately every 28 days. Additionally the test chambers provided a continuous flow of N_2 and periodic addition of water vapor to maintain the test environment. The flight film was sealed in a small volume of nitrogen and thus established a constant equilibrium with the film. Latent image test data for film stored at 70°F for a period approximating that of the flight film loads were used for comparison and are shown in Table 4-13b. The test data show a much greater latent image fading than experienced by the flight film. This difference was attributed to the periodic exposure of the test film to air since air accelerates latent image fading compared to a constant nitrogen environment.

Little or no sensitivity loss was expected to have occurred for the flight 026-02 film loads, but no flight film sensitivity data were available.

4.13 Performance Evaluation, Film Type 3401

Kodak PLUS-X Aerial Film, Type 3401 was used in two Skylab experiments; S191, Infrared Spectrometer Viewfinder Tracking System and S233, Kohoutek Photometric Photography.

This film was used in the S191, 16-mm Data Acquisition Camera to photographically recorded the field of view of the infrared spectrometer. Analysis of the imagery immediately following the SL2 mission showed some difficulty in scene identification because of film graininess inherent

from processing in D-19 developer. Although, the film was still considered adequate for scene identification, it was judged that better quality and interpretability could be obtained using color film. Therefore, the use of type 3401 film on this experiment S191 was limited to two 140-ft rolls on the SL2 mission.

Experiment S233 used 4 rolls of 3401 (35-mm x 9-ft) in an Operational 35-mm Nikon camera. These rolls were launched and returned on SL4 to coincide with comet Kohoutek's most active period. The objective of this experiment was to obtain a series of visible light photographs of the comet Kohoutek suitable for photometry and to provide a photographic history of the comet. The 3401 film provided data which was adequate for this experiment, but post-mission evaluation showed a faster film was desirable. Film photometry analysis was complicated by low intensity reciprocity failure since preflight sensitometric exposures were made at an exposure time of 1/50 second and flight data exposures at 60 and 120 seconds. Postflight sensitometry was exposed at 60 seconds with the light intensity reduced so the exposure value at each step was the same as the preflight data. In order to perform photometric analysis the preflight sensitometry had to then be adjusted for reciprocity failure. These adjustments were made and are reported in reference 4v. The adjustments were, however, complicated by not knowing what effect the Skylab environment had on the reciprocity failure. Therefore, it was recommended that the photometry be calibrated using the postflight calibration sensitometry only. Data analysis personnel also recommended that preflight reciprocity testing be conducted for future experiments employing long exposure time and calibration sensitometry be extended to cover the exposure time range of such experiments.

4.13.1 Environmental Analysis Results, 3401

Environmental timelines and H & D curves for this film are given in Appendix D, Figures D-49 through D-54. Only FLIGHT PRE and FLIGHT POST data were available for rolls BH01 and BH02. It should also be noted, that the curves plotted for rolls BH03 through BH06 represent data recorded directly from film measurements and have not been adjusted for reciprocity failure. Therefore, the CONTROL and PRE curves are labeled as 1/50 second exposures and the POST curves as 60 second exposures. It was not meaningful to relate differences in these curves directly to environmental effects since the major effects were caused by reciprocity failure. However, analysis of these sensitometric data was accomplished. The analysis results are given in Table 4-14 and summarized below.

Fogging of the flight film due to the Skylab environment varied from 0.15 density on Roll BH02 to 0.27 density on Rolls BH05 and BH06. The fogging was generally consistent with the Flight Data Calculated Dose

TABLE 4-14. ANALYSIS RESULTS, FILM TYPE 3401

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	TEST DATA* PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
BH01	+	0.761	0.17	0.19
BH02	+	0.658	0.14	0.15
BH03	+	1.812	0.27	0.26
BH04	+	1.812	0.27	0.24
BH05	+	1.817	0.27	0.27
BH06	+	2.185	0.31	0.27

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
BH01	+	+	+	+	+	+	+	+
BH02	+	+	+	+	+	+	+	+
BH03	-0.16	-0.19	-0.03	0.02	-0.13	-0.21	+	+
BH04	-0.15	-0.14	-0.01	0.09	-0.14	-0.23	+	+
BH05	-0.15	-0.14	-0.04	0.04	-0.11	-0.18	+	+
BH06	-0.20	-0.25	-0.06	-0.02	-0.14	-0.23	+	+
Average	-0.165	-0.18	-0.035	0.032	-0.13	-0.213	+	+

c. FILM SENSITIVITY AND RECIPROCITY FAILURE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM RESULTS CONTROL-FLIGHT POST AT DENSITY:		RECIPROCITY FAILURE EFFECT CONTROL-HOUSTON POST AT DENSITY:		FLIGHT EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
BH01	+	+	+	+	+	+
BH02	+	+	+	+	+	+
BH03	-0.50	-0.44	-0.36	-0.24	-0.14	-0.20
BH04	-0.49	-0.44	-0.36	-0.23	-0.13	-0.21
BH05	-0.53	-0.44	-0.38	-0.26	-0.15	-0.18
BH06	-0.53	-0.53	-0.39	-0.30	-0.14	-0.23
Averages	-0.513	-0.463	-0.373	-0.258	-0.140	-0.205

*Based on Pre-mission test data using Flight Data Calculated Dose

+ No data available.

(see Table 4-14a) but the nature of their relative variations illustrates the statistical variation between the calculated and actual dose for each roll of film.

Latent image fading analysis was limited to rolls BH03 through BH06 because no CONTROL curves were available for rolls BH01 and BH02. This analysis showed an average latent image loss of approximately 1/2 f stop. Evaluations using the HOUSTON PRE data indicated that at 0.6 density above fog 80% of this effect was caused by radiation fogging. At 1.2 density the radiation effects were larger than the net effect on the flight film. However, this was offset by an opposing temperature effect. These results shows that the actual fading of the latent image was very small and the effect seen was a reduction in film sensitivity due to film fogging. Although these effects were small, they must be considered in obtaining precise photometry.

Film sensitivity effects could not be calculated directly because of the exposure time differences of the CONTROL and the post-mission sensitometry. However, the H & D curves for rolls BH01 and BH02 show this film was very stable. Therefore, it was approximated that the HOUSTON CONTROL was approximately the same as the CONTROL would have been if exposed at 60 seconds. Using this assumption, Table 4-14C provides the following result columns:

a. Flight Film Results - Show the total loss of sensitivity due to both reciprocity failure and environment.

b. Reciprocity Failure Effects - Approximates the loss of film sensitivity at the specified densities caused by the difference in exposure time (1/50 vs 60 seconds).

c. Flight Effects - Approximates the loss of sensitivity due to the Skylab environment. Primarily due to the effect of radiation fogging.

Based on this assumption the loss of sensitivity averaged approximately one f stop due to reciprocity failure, 1/2 f stop due to the flight environment yielding a total effect of approximately 1 1/2 f stops.

4.13.2 Comparison of Flight and Test Data, 3401

This comparison was done for only radiation fogging data because film type 3401 was not included in the pre-mission temperature and humidity tests. Comparison of the radiation fogging data was done by tabulating the fog increase given by the pre-mission test results for each Flight Data Calculated Dose (see Table 4-14a). Comparison of the

resultant values to the increase in fog measured on the flight film shows excellent correlation and agreement.

4.14 Performance Evaluation, Film Type 2403

Kodak TRI-X AEROGRAPHIC Film, Type 2403 was a candidate film for Skylab during the planning phase of several Skylab experiments and was tested as part of the Skylab pre-mission environmental tests for its response to both CO^{60} gamma rays and several environmental test conditions. This film was, however, replaced with TRI-X Recording Film, Type SO-265 shortly before the SL1 launch. Therefore, type 2403 was not launched on any of the Skylab missions. Test data on this film type are given in references 6b and 6c.

4.15 Performance Evaluation, Film Type SO-265

Kodak TRI-X Recording Film, Type SO-265 was a special order film produced in a limited quantity for an application outside the Skylab program. This film type was substituted for TRI-X AEROGRAPHIC Film, Type 2403 late in the mission preparation to eliminate light piping and reduce halation. The SO-265 also had Rem Jet backing which reduced electrostatic discharge during vacuum operation. Due to the special nature of this film and lack of general application Kodak discontinued its production in March 1975.

Film type SO-265 was used for Experiments T025, Coronagraph Contamination Measurement and S063, UV Airglow Horizon Photography. S063 also use other film types in addition to SO-265. This film fulfilled the experiment and data analysis requirements and was judged as the best available film for the T025 application. However, a film with higher speed, finer grain and greater latitude was desired. Emulsion cracking was observed during the data analysis. This phenomenon was caused by transporting the film in the Electric Nikon during EVA activities after the emulsion had become brittle due to the vacuum of space. This anomaly did not effect the data analysis. Substantial data loss was, however, encountered due to operational difficulties of the Nikon cameras.

Several recommendations were made by the scientists who analyzed data recorded with this film. These recommendations were directed mostly toward obtaining better calibration. Specifically, it was recommended that in-flight calibration be performed to quantify the change in photographic properties as a function of time; that more accurate film calibration be done and that film spectral sensitivity tests be conducted to provide more data for absolute spectral sensitivity and spectral response changes. It was also recommended that reciprocity effects be more adequately considered and tested.

4.15.1 Environmental Analysis Results, SO-265

Twelve rolls (35-mm x 7-ft) of SO-265 film were launched for use on Skylab but only eight were used and returned. All rolls were launched and returned on SL4. Three rolls (BE03, BE11 and BE16 were selected for environmental effects analysis as representative of the SL4 environmental effects. Environmental timelines and H & D curves for these rolls are given in Appendix D, Figures D-55 through D-57. HOUSTON PRE and POST data were available for only rolls BE11 and BE16. Numerical analysis results based on these curves are given in Table 4-15.

TABLE 4-15. ANALYSIS RESULTS, FILM TYPE SO-265

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
BE03	+	2.113	+	0.54
BE11	+	2.107	+	0.54
BE16	+	1.789	+	0.54

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.0 ABOVE FOG	0.6 ABOVE FOG	1.0 ABOVE FOG	0.6 ABOVE FOG	1.0 ABOVE FOG	0.6 ABOVE FOG	1.0 ABOVE FOG
BE03	-0.70	-1.09	+	+	+	+	+	+
BE11	-0.67	-1.08	-0.06	-0.07	-0.61	-1.01	+	+
BE16	-0.67	-0.96	-0.06	-0.05	-0.61	-0.91	+	+
Average	-0.67	-1.02	-0.06	-0.06	-0.61	-0.96	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.0 ABOVE FOG	0.6 ABOVE FOG	1.0 ABOVE FOG	0.6 ABOVE FOG	1.0 ABOVE FOG
BE03	-0.39	-0.78	+	+	+	+
BE11	-0.43	-0.85	0.03	0.06	-0.46	-0.91
BE16	-0.40	-0.69	0.02	0.06	-0.42	-0.75
Average	-0.415	-0.77	0.025	0.06	-0.44	-0.83

+ No data available.

The Radiation Data Comparison, Table 4-15a, shows that all three rolls had the same density increase in base plus fog even though the calculated radiation dose values were different. This variance is attributable to the inaccuracy of the calculated dose. Film fogging in a reduction of the film density range of about 25% with a comparable reduction in contrast.

The Latent Image Effects results, Table 4-15b, show an apparent latent image loss of more than 2 f stops at 0.6 above fog and 3 f stops at 1.0 above fog. However, comparisons of flight data with HOUSTON PRE data show that only about 1/4 f stop of this change was due to latent image fading and the rest due to the effects of radiation. The net effect was a 2 to 3 f stop effective loss in sensitivity of pre-exposed imagery. A similar effect was observed for the change in film sensitivity. The change in film sensitivity due to storage time, temperature and humidity over the SL4 mission as shown by the HOUSTON POST data was ~ 1/4 f stop. However, the net effect, due primarily to radiation, was to reduce the film sensitivity by an average of 1 1/2 f stops at 0.6 above fog and 2 1/2 f stops at 1.0 above fog. These effects account, in part, for the inability of the film to detect faint atmospheric clouds observed and photographed by the astronauts but not imaged on the flight film.

4.16 Performance Evaluation, Film Type 2485

Kodak 2485 High Speed Recording Film was the fastest film used in orbit during the Skylab missions. It was, therefore, used on several experiments for detection and recording of low light level phenomena. These experiments were:

S063	UV Airglow Horizon Photography
S073	Gegenschein/Zodiacal Light
S232	Barium Plasma Observations
T027	Contamination Measurement

The objectives of these experiments are given in Appendix B. Twenty-eight rolls of 2485 launched and 22 returned. Nine of these rolls were selected for environmental effects analysis; two from SL1/2, four from SL3 and three from SL4. Two rolls selected from SL1/2 and one roll from SL3 were 16-mm by 7-ft. The remaining film rolls analyzed were 35-mm x 7-ft. long.

Principal Investigators of experiments that used this film reported this film was the best available for these applications. It was found to be adequate for daylight photography but reciprocity failure and loss of sensitivity were too great for good night time photos. The film was

reported to have macro grain clumping which caused a loss in resolution and density changes due to varying pressure during spooling in the flight cartridges. Considerable fogging was observed on some rolls. 16-mm rolls used in the vacuum of space showed numerous static electric discharge images. These appeared as both high density fine lines originating from the film edge and perforations and as random general fog regions with little or no structure. The latter of these suggests electrostatic discharge at the film supply roll as the film was unwound.

Based on the above observation it was recommended that future low light photographic detection experiments investigate the effects of reciprocity failure as well as film environmental effects as a part of the film selection procedure. This should be followed by test exposures using flight cameras and film under simulated lighting and environmental conditions. Particular attention should be given to electrostatic degradation for cameras to be operated in vacuum.

4.16.1 Environmental Analysis Results, 2485

Environmental timelines and H & D curves for 2485 flight rolls BV01, BV02, BV07, BV13, BV15, BV22, BV26 and BV29 given in Appendix D, Figures D-58 through D-66. It is noted that no Houston Control data was available for rolls BV01, BV02 and only the FLIGHT PRE and GROUND CONTROL were available for roll BV07.

The relatively large increase in base plug fog of this film and the small total radiation dose shown on the timelines indicate this film was also the most sensitive film to ionizing radiation. These data show a reduction of film density range of 27 to 50% due to film fogging. This was expected based on premission tests. However, the Radiation Data Comparison analysis results given in Table 4-16a show the fogging of the flight film was less than expected even though the Flight Data Calculated Dose was larger than the pre-mission prediction. Therefore, analyses were made of the pre-mission test data using the Flight Data Calculated Dose. These are indicated by an asterisk in the Table 4-16a. These results show the flight fogging was 24 to 37% less than that derived from test data. This difference is partially attributable to the difference in the effect of CO^{60} gamma rays, used to expose the test data, and the lower energy space radiation spectrum. Roll BV01 was not considered in this calculation due the variance of the Flight Data Calculated Dose for this roll with the rest of the data. The timeline for this roll shows large dose contributions for days when the T027 camera was used outside the Skylab. If these large dose spikes are neglected the resultant radiation dose becomes consistent with the fog increase observed on the film. It was, therefore, assumed that the computer model used an incorrect shielding factor for the T027 camera during its external operation.

TABLE 4-16. ANALYSIS RESULTS, FILM TYPE 2485

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
BV01	+	1.692	1.66*	0.64
BV02	+	0.55	0.80*	0.56
BV07	+	0.944	1.13*	0.86
BV13	0.934	1.012	0.98	0.84
BV14	0.934	1.028	0.98	0.93
BV15	0.934	0.961	0.98	0.83
BV22	+	1.475	1.50*	1.06
BV26	+	1.49	1.53*	1.04
BV29	+	1.685	1.65*	1.04

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
BV01	-0.27	-0.45	+	+	+	+	-0.04	-0.04
BV02	-0.27	[illegible].42	+	+	+	+	-0.04	-0.04
BV07	-0.50	[illegible].01	+	+	+	+	-0.02	-0.03
BV13	-0.55	-0.78	-0.04	-0.02	-0.51	-0.76	-0.02	-0.03
BV14	-0.62	-0.78	-0.06	-0.06	-0.56	-0.72	-0.02	-0.03
BV15	-0.53	-0.73	-0.06	-0.06	-0.47	-0.67	-0.02	-0.03
BV22	-0.77	-1.52	-0.04	-0.04	-0.73	-1.48	+	+
BV26	-0.76	-1.54	-0.08	-0.06	-0.68	-1.48	+	+
BV29	-0.84	-1.53	-0.05	-0.04	-0.79	-1.49	+	+
Average	-0.678	-1.147	-0.055	-0.047	-0.623	-1.10	-0.027	-0.033

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
BV01	-0.60	-1.34	+	+	+	+
BV02	-0.42	-0.62	+	+	+	+
BV07	+	+	+	+	+	+
BV13	-0.41	-0.78	-0.11	-0.05	-0.52	-0.73
BV14	-0.36	-0.50	-0.06	-0.03	-0.30	-0.47
BV15	-0.42	-0.76	-0.06	-0.03	-0.36	-0.73
BV22	-0.97	-1.52	0	0.04	-0.97	-1.56
BV26	-0.88	-1.54	-0.03	0.02	-0.85	-1.56
BV29	-0.86	-1.53	-0.02	0.01	-0.84	-1.54
Average	-0.65	-1.105	-0.01	-0.006	-0.64	-1.098

* Based on pre-mission test data at flight data calculated dose.
\+ No data available.

Latent Image Effects results, tabulated in Table 4-16b show environmental effects similar to those observed for film type SO-265. These data indicated very little fading of the latent image ($< \frac{1}{4}$ f stop). However, at 0.6 above fog, the increase in base plug fog due to radiation caused a reduction of sensitivity of the pre-exposed sensitometry by 1 to almost 3 f stops, depending on radiation dose. At 1.2 above fog, the loss was equivalent to $1\frac{1}{2}$ to 5 f stops. 92% of the image loss was due to radiation effect at 0.6 above fog, and 96% at 1.2 above fog. The threshold of detection for these rolls was also reduced by 1 to 2 f stops.

A change in film sensitivity was observed which followed the same pattern as the latent image loss, i.e., a random, almost insignificant sensitivity change was present due to storage time and temperature but a large reduction in the overall response of the film was caused by the radiation fogging. These losses varied from 1 to over 3 f stops at 0.6 above fog and from almost 2 to 5 f stops at 1.2 above fog. Sensitivity losses were proportional to the film fogging and radiation levels. On the average, 99% of the loss of sensitivity was due to the effects of ionizing radiation and only 1% due to storage time, temperature and relative humidity.

4.16.2 Comparison of Flight and Test Data, 2485

Comparison of flight data for this film was accomplished using the pre-mission test data for film type SO-166. This was the same film as type 2485 but had a special order identification number prior to becoming a Kodak production product. Comparison of the ionizing radiation effects results showed the flight film increase in fog was 24 to 37% less than that predicted by the test data. Flight data calculated doses for the SL3 mission were only about 6% higher than predicted. The temperature/humidity test data for latent image fading, Table 4-16b, were comparable with the FLIGHT minus HOUSTON PRE data. This supports the conclusion that very little latent image fading occurred and apparent latent image effects observed were caused by fogging due to ionizing radiation.

4.17 Performance Evaluation, Film Type 2424

Kodak Infrared AEROGRAPHIC Film, Type 2424, was used in the Skylab Multispectral Photographic Camera, Experiment S190A. As discussed in paragraph 4.11 this camera had six camera stations, each imaging in a separate spectral band on separate 70-mm by 110-ft film rolls. Film type 2424 was used in camera stations 1 and 2 which recorded imagery of the earth's surface in the spectral bands of 700 to 800 nm and 800 to 900 nm, respectively.

To achieve radiometric calibration, each roll of film was provided with both broadband and spectral sensitometric images before and after each mission. The broadband sensitometric images were recorded with a Wratten 89B filter in the sensitometer to simulate the operational spectrum for this film. Analysis of the broadband sensitometric images was the basis for the environmental effects analysis.

A total of thirty-two cassettes of 2424 film were launched for use in the S190A camera. Six cassettes were launched on SL1 on 5/14/73, stowed in the OWS film vault. Due to the anomalous environmental conditions on SL1 prior to SL2 launch, two new cassettes were launched on SL2 to replace film possibly damaged during the orbital storage period. Four cassettes of 2424 from the SL1 launch and the two resupplied on SL2 were used for SL2 on-orbit photography. Camera stations, magazine numbers, and mission launch for all 2424 film used during Skylab are listed below.

Camera Station	Film Roll Number	Launch
1	1	SL2
1	7, 13	SL1
2	2	SL2
2	8, 14	SL1
1	19, 25, 31, 37, 43	SL3
2	20, 26, 32, 38, 44	SL3
1	49*, 55, 61, 67, 73, A1, B1	SL4
2	50*, 56, 62, 68, 74, A2, B2	SL4

Due to a procedural error, filters were inadvertently not installed on the camera for EREP passes 53 through 62. Therefore, film rolls marked with an asterisk were exposed without filters and provided broadband imagery limited only by the spectral sensitivity of the film. Under these conditions the data from camera stations 1 and 2 were identical. Therefore, roll 49 required special processes to compensate for the overexposure caused by omission of the filter. No data was available for Roll 50.

4.17.1 Environmental Analysis Results, 2424

Environmental timelines and H & D curves on which the 2424 analysis was based are presented in Appendix D, Figure D-67 through D-78. Table 4-17 presents the environmental degradation effects exhibited by these curves. Table 4-17a shows that the increase in base + fog varied from 0.13 density units for film launched on SL2 to 0.38 units for film used on SL4. Pre-mission predictions of radiation dose were 18 to 30% less than those calculated during the mission.

Table 4-17b gives data from which latent image effects were determined. The averages of data for film used on each mission showed a net latent image growth of ~½ f stop for SL 1/2, ¼ f stop for SL3 and 1/8 f stop for SL4. The effects of storage time, temperature and humidity and radiation were additive for SL 1/2 and SL3, but opposing for SL4. The radiation caused a latent image growth during all missions. The time, temperature and humidity effect contributed to the image growth for SL 1/2 and SL3 but decreased the image growth during SL4.

This indicates that the effect of storage time and temperature on this film was to first cause a latent image growth and then a latent image fading with increasing time. This phenomenon was partially supported by the pre-mission test data.

Film sensitivity effects were determined by the analysis of post-mission sensitometric curves. The results are summarized in Table 4-17c. Storage time, temperature and humidity produced a decrease in sensitivity as did the ionizing radiation. This decrease prevailed for all film rolls evaluated. The net loss in sensitivity varied from ½ f stop on rolls 1, 2 and 43 to 1½ f stops on rolls 13 and 14 measured at a density of 1.2 above fog.

4.17.2 Comparison of Flight and Test Data, 2424

Pre-mission comparative test data were available for the separate effects of ionizing radiation and temperature-humidity but not for the simultaneous combination of these effects. The ionizing radiation comparison is given in Table 4-17a. As discussed above the pre-mission predicted doses were 20 to 30% lower than the flight data calculated doses. The actual increase in base plug fog, on the other hand, varied from 35% higher to 9% lower than the pre-mission predicted increase in fog. This apparent variance was expected since the actual base plus fog includes the effect of time, temperature and humidity. Therefore, the test and flight radiation effects data were considered to be in good agreement.

Pre-mission temperature-humidity test data indicates latent image growth for the majority of conditions tested. In general the higher the test temperature and the longer the test period, the greater is the latent image growth. Although no latent image fading was observed from pre-mission testing, as was the case for the SL4 flight data, the longest test period was only half as long as the storage period for the SL4 film. The effects were, however, consistent for common test and flight storage periods.

TABLE 4-17 ANALYSIS RESULTS, FILM TYPE 2424

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED INCREASE IN BASE PLUS FOG (Film Density)	ACTUAL INCREASE IN BASE PLUS FOG (Film Density)
1	0.388	0.472	0.12	0.13
2	0.388	0.472	0.12	0.14
13	0.463	0.653	0.14	0.19
14	0.463	0.653	0.14	0.17
25	0.728	0.996	0.24	0.22
26	0.728	0.996	0.24	0.22
43	0.723	0.944	0.24	0.23
44	0.723	0.944	0.24	0.23
55	+	1.550	0.24 *	0.30
56	+	1.550	0.24 *	0.31
B1	+	1.905	0.28 *	0.38
B2	+	1.905	0.28 *	0.35

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1	0.11	0.14	0.01	0.09	0.10	0.05	-0.01	0
2	0.10	0.13	0.06	0.09	0.04	0.04	-0.01	0
13	0.18	0.18	0	0.08	0.18	0.10	0.14	0.13
14	0.11	0.17	0.01	0.07	0.10	0.10	0.14	0.13
25	0.06	0.06	0.04	0.09	0.02	-0.03	0.02	0.03
26	0.09	0.09	0	0.07	0.09	0.02	0.02	0.03
43	0.08	0.05	0.03	0.06	0.05	-0.01	0.02	0.03
44	0.06	0.06	0	0.05	0.06	0.01	0.02	0.03
55	0.04	0.06	-0.13	-0.12	0.17	0.18	0.08	0.06
56	0.02	0.04	-0.15	-0.14	0.17	0.18	0.08	0.06
B1	-0.03	-0.01	-0.17	-0.14	0.14	0.13	0.08	0.06
B2	0	0.03	0.04	0.11	-0.04	-0.08	0.08	0.06

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG	0.6 ABOVE FOG	1.2 ABOVE FOG
1	-0.11	-0.15	0.03	0.06	-0.14	-0.21
2	-0.15	-0.17	0.03	0.04	-0.18	-0.21
13	-0.36	-0.47	-0.08	0.01	-0.28	-0.48
14	-0.35	-0.42	-0.05	-0.07	-0.30	-0.35
25	-0.21	-0.20	-0.08	-0.06	-0.13	-0.14
26	-0.20	-0.21	-0.08	-0.07	-0.12	-0.14
43	-0.16	-0.18	-0.08	-0.07	-0.08	-0.11
44	-0.19	-0.19	-0.10	-0.07	-0.09	-0.12
55	-0.28	-0.30	-0.13	-0.12	-0.15	-0.18
56	-0.27	-0.28	-0.13	-0.13	-0.14	-0.15
B1	-0.18	-0.23	-0.17	-0.15	-0.01	-0.08
B2	-0.23	-0.24	-0.14	-0.13	-0.09	-0.11

* Based on pre-mission test data at flight data calculated dose.
\+ No data available.

During data analysis, it was observed that the HOUSTON PRE sensitometric curves for SL4 rolls 55, 56 and B1 were inconsistent with the rest of the 2424 film rolls. The cause of this anomaly was not discovered but caution should be used in applying results based on these curves.

4.18 Performance Evaluation, Film Type SO-242

Kodak Aerial Color Film, Type SO-242, was a high resolution color reversal film with good color saturation for high contrast. This film was used during each Skylab mission in the Earth Terrain Camera, Experiment S190B, and on SL4 in the X-Ray Telescope, Experiment S056. The S190B Experiment used 9 rolls (5-inch x 210-ft); one on SL2 and 4 each on SL3 and SL4. Experiment S056 used a single 35-mm by 1000-ft roll.

SO-242 film use in S190B produced high quality images of the earth with ground resolution of 18 to 25 meters on second generation film. Roll 84 showed random faint yellow streaking approximately 2 mm wide due to an emulsion defect in the film. However, this phenomenon was not observed on other rolls of this film type. Minimal color shift was observable at high densities due to the effect of ionizing radiation on the film color layers. In this case, the blue layer experienced a reduction in maximum density of up to 27% of its total density range while the red and green layers were virtually unaffected. This film performed the requirements of S190B adequately but the resolution of the camera was film limited.

Type SO-242 film was used on the X-Ray Telescope, Experiment S056, as an experiment to determine if spectral definition could be accomplished by color separation analysis of the film. This film had the advantage of better spatial resolution than the SO-212 film used previously as well as the potential for wavelength separation. However, the color film was also found to have several disadvantages. The SO-242 was very slow and had the standard gelatine overcoat over the film emulsion. Therefore, many X-rays were absorbed before reaching the photosensitive emulsion and only intense X-ray radiation from solar flares were recorded. The color film also had less dynamic range than the black and white film used previously. Over the period of data analysis, film color dye fading was defined to be a problem because of the color separation density variation with time and the long time required to complete the data analysis. Spectral distribution identification by color separation analysis has been unsuccessful to date because of color dye fading, the apparent lack of color shift in the solar imagery and a lack of basic laboratory data to establish the color film response to various soft X ray wavelengths and spectral distributions. Based on these results, Dr. J. Underwood, co-principal investigator for Experiment S056, described

this film as basically unsatisfactory in this application without additional laboratory research. Additionally, he defined a need for more and better film calibration in the soft X-ray spectral region and recommended that an X-ray sensitometer with better wavelength selectivity and shorter exposure times be developed.

4.18.1 Environmental Analysis Results, SO-242

Environmental analysis of this film was based on S056 film load 5 and S190B film rolls 81, 83, 88, 90 and 94. Environmental timelines and H & C curves for these rolls are given in Appendix D, Figures D-79 through D-84. The H & D curves were plotted from density data measured with visual, red, green and blue filters in the densitometer. The visual (photopic) filter data is representative of the total density observed by the human eye while the red, green and blue filter data give densities of each color layer in the film. Numerical analysis results for these rolls are given in Table 4-18. These results were based on analysis of the H & D curves derived from measurements with the visual filter in the densitometer.

Evaluation of the H & D curve shows the decrease in maximum density due to space radiation was negligible for all but the emulsion layer measured with the blue densitometer filter. This layer showed reductions in maximum density of 0.70 for roll 81, 0.38 for rolls 83 and 88, 0.54 for roll 90, 0.60 for roll 94 and 0.70 for load 5. These reductions in maximum density were approximately proportional to the Flight Data Calculated Dose listed in Table 4-18a. The larger effect on the blue sensitive emulsion layer was expected due to the higher sensitivity of this layer to ionizing radiation. This high sensitivity is required in this film to achieve proper color balance of visible light exposures with the emulsion stacking order of this film.

Latent image evaluation of this film type showed fading of approximately 1/3 to 1/2 f stops. Comparisons of the HOUSTON PRE control data and the flight data showed that approximately 80 to 90% of the image fading was due to the effects of storage time and temperature for the S190B rolls flown on SL3 and SL4. Load 5 and roll 81 showed an apparent latent image growth in the Radiation Effects column in Table 4-18b. However, this was caused by an increase in the maximum density value of the flight film which opposed the effect of storage time, temperature and relative humidity and reduced the total observed latent image fading.

Film sensitivity analysis showed a very small increase in sensitivity primarily due to the effects of radiation. The affect was less than 1/4 f. stop and therefore was considered negligible. Numerical results are given in Table 4-18c.

TABLE 4-18. ANALYSIS RESULTS, FILM TYPE SO-242

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
Load 5	+	2.05	+	< 0.01
81	0.979	0.560	0.19	< 0.01
83	1.72	1.101	0.31	< 0.01
88	1.64	1.031	0.30	0.02
90	+	1.632	+	< 0.01
94	+	1.468	+	< 0.01

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
Load 5	-0.06	-0.06	-0.17	-0.15	0.11	0.09	+	+
81	-0.10	-0.09	-0.16	-0.17	0.06	0.08	+	+
83	-0.12	-0.13	-0.12	-0.10	0	-0.03	+	+
88	-0.15	-0.18	-0.12	-0.12	-0.03	-0.06	+	+
90	-0.17	-0.14	-0.12	-0.08	-0.05	-0.06	+	+
94	-0.16	-0.16	-0.12	-0.13	-0.04	-0.03	+	+
Average	-0.126	-0.126	-0.135	-0.125	0.008	-0.01	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
Load 5	0.05	0.01	+	+	+	+
81	0.05	0.04	0.05	0.03	0	0.01
83	0.06	0.05	-0.07	-0.05	0.13	0.10
88	0.06	0.01	0.01	0	0.05	0.01
90	0.05	0.08	0.01	0.04	0.04	0.04
94	0.06	0.04	-0.01	0	0.07	0.04
Average	0.056	0.044	-0.002	0.004	0.058	0.04

+ No data available.

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It should be noted that although load 5 was operated in a vacuum for approximately 50 days the photographic performance and environmental effect were comparable to the film rolls used inside the Skylab. Noticeable differences were minor but were observable as variations in latent image effects.

4.18.2 Comparison of Flight and Test Data, SO-242

Test data available for comparative analysis was limited to the fogging predictions and pre-mission radiation dose calculations. Examination of Table 4-18a shows that pre-mission predicted radiation dose was approximately 1.6 to 1.7 times that calculated during the mission. This was within the Vette model error but was larger than most film dose comparisons. The predicted decrease in maximum density was grossly different from that actually measured. It should be noted, however, that the pre-mission prediction was based on film Type SO-121 test data since SO-242 was introduced after the pre-mission radiation testing was completed. However, the actual decrease in maximum density were still less than expected.

4.19 Performance Evaluation, Film Type SO-356

Kodak High Definition Ektachrome Film, Type SO-356, was the same emulsion as SO-242 but was coated on 4 mil ESTAR base. This film was used in Station 4 of the Skylab Multispectral Photograph Camera, Experiment S190A. This station employed only a haze filter and, therefore, had a spectral coverage of 400 to 700 nm.

Seventeen cassettes of SO-356, each 70-mm x 110-ft, were launched for use during the Skylab mission. Two cassettes launched on SL1 were, however, not used due to potential degradation from the high OWS temperatures. Three rolls of fresh film were launched on SL2 and used in their place. Therefore, a total of fifteen rolls were used and returned. The SO-356 rolls used are listed below by film roll number and launch.

Film Roll Number	Launch
04, 10, 16	SL2
22, 28, 34, 40, 46	SL3
52, 58, 64, 70, 76, A4, B4	SL4

Due to a procedural error, the filter was inadvertently not installed when roll 52 was used. This caused only a slight overexposure of imagery on that roll which was compensated for in the film processing. Due to this minor change in processing, the sensitometric data for this roll were not considered in this environmental effects analysis.

SO-356 film performed the requirements of this experiment very well and no film anomalies were observed. As a result, high quality images of the earth were obtained. Each frame provided ground coverage of a square area approximately 100 miles on each side with ground resolution of about 37 meters for second generation duplicate film.

4.19.1 Environmental Analysis Results, SO-356

Environmental analysis of this film was based on environmental time-lines and H & D curves for rolls 04, 16, 22, 46, 58 and B4 given in Appendix D, Figures D-85 through D-90. The response of this film to the Skylab environment was essentially the same as that observed for SO-242.

As shown in Table 4-19, the pre-mission dose prediction was 1.6 to 1.9 times that calculated during flight. The actual decrease in maximum density for the visual, red, and green measurements were negligible while a larger effect was observed in the blue. This effect was relatively small and caused minimal color shift at high densities. As was observed from the SO-242 data, the actual decrease in maximum density did not compare well with and was much less than the pre-mission test data based on film Type SO-121.

Latent image effects analysis showed image losses of approximately 1/4 f stop for SL2 film and 1/2 to 2/3 f stop for SL3 and SL4. These small losses were attributable almost entirely to storage time, temperature and relative humidity. Test data comparison values shown in Table 4-19b were based on tests of film Type SO-121. These data imply that SO-121 was less susceptible to latent image fading than SO-356.

Film sensitivity analysis results, Table 4-19c, showed a small increase in sensitivity (approximately 1/4 f stop) for the film rolls flown on SL2 and a negligible decrease in sensitivity for those used on SL3 and SL4. Comparison of the temperature/humidity and radiation effects indicated that, except for SL2, these environmental parameters caused opposing effects resulting in a very small net sensitivity change.

4.20 Performance Evaluation, Film Type SO-368

Kodak Ektachrome MS Film, Type SO-368, was a medium speed color reversal film generally processed at an ASA of 64. This film was used during Skylab primarily for external hand-held photography to document crew and operational activity. It was also used on Experiments T053, S063 and S191. These multi-disciplinary applications required that this film be used in 16-mm Data Acquisition Cameras, Operational 35-mm Nikons and 70-mm Hasselblad Cameras. The number of rolls launched and returned of each size is given in Table 4-1. Although 60 rolls of SO-368 were used on Skylab, complete sensitometric data were available for only a few 16-mm and 70-mm rolls.

TABLE 4-19. ANALYSIS RESULTS, FILM TYPE SO-356 (VISUAL)

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
04	0.893	0.472	0.02	< 0.01
16	0.898	0.463	0.02	< 0.01
22	1.630	0.998	0.30	< 0.01
46	1.596	0.944	0.29	< 0.01
58	+	1.550	+	< 0.01
B4	+	1.905	+	< 0.01

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
04	-0.07	-0.04	-0.05	-0.08	-0.02	0.04	-0.04	-0.01
16	-0.07	-0.03	-0.09	-0.08	0.02	0.05	-0.04	-0.01
22	-0.20	-0.18	-0.19	-0.21	-0.01	0.03	-0.04	-0.03
46	-0.18	-0.15	-0.18	-0.16	0	0.01	-0.04	-0.03
58	-0.20	-0.18	-0.17	-0.15	-0.03	-0.03	-0.04	-0.04
B4	-0.14	-0.13	-0.14	-0.13	0	0	-0.04	-0.04
Average	-0.143	-0.118	-0.137	-0.135	-0.007	0.016	-0.04	-0.027

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
04	0.08	0.08	0	0.04	0.08	0.04
16	0.10	0.10	0	0.03	0.10	0.07
22	0	-0.01	-0.08	-0.07	0.08	0.06
46	-0.02	-0.01	-0.07	-0.06	0.05	0.05
58	-0.02	-0.01	-0.04	-0.04	0.02	0.03
B4	-0.02	0	-0.04	-0.05	0.06	0.05
Average	0.027	0.025	-0.038	-0.025	0.065	0.05

+ No data available.

This film was determined to be adequate for the applications for which it was used and no significant film problems or anomalies were reported.

4.20.1 Environmental Analysis Results, SO-368

Environmental analysis was based on H & D curves for 12 rolls of film. The rolls are identified below by roll number, film size, and mission on which they were launched and returned.

Roll Number	Size	Mission
CX01	16-mm	SL2
CX03	16-mm	SL2
CX04	70-mm	SL2
CX05	70-mm	SL2
CX06	70-mm	SL2
CX07	16-mm	SL3
CX09	16-mm	SL3
CX10	70-mm	SL3
CX17	70-mm	SL4
CX23	70-mm	SL2
CX27	70-mm	SL3
CX52	70-mm	SL4

H & D curves and environmental timelines for these rolls are given in Appendix D, Figures D-91 through D-102. Although some of these rolls were used during extra-vehicular activity, the time in the space vacuum is not shown on the environmental timelines due to the short duration of vacuum exposure. It should also be noted that the HOUSTON PRE and POST data were not available for several rolls.

Changes in maximum density due to space radiation are given in Table 4-20a. Variations of actual decrease in maximum density compared to the Flight Data Calculated Dose show the statistical variation of the calculated dose. This was illustrated by comparison of these parameters for rolls CX04, CX05 and CX06. In this case, the calculated dose was identical while the change in maximum density varied by over a factor of two. Although reduction of maximum density for this film was as large as 0.66 density units no observable data loss was identified. Additionally, the space radiation caused comparable reduction of maximum density for each of the three emulsion layers. Therefore, no color shift was observed.

Evaluation of the environmental effects on the film latent image showed negligibley small effects for film flown on SL2. Reduction in film response of up to 3/4 f stop was observed at 1.2 below maximum density on SL3 and SL4 film data. Detailed analysis showed this effect was due to the reduction of maximum density due to exposure by ionizing radiation rather than to temperature/humidity effects.

TABLE 4-20 ANALYSIS RESULTS, FILM TYPE SO-368 (VISUAL)

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
CX01	+	0.75	0.20*	0.15
CX03	+	0.75	0.20*	0.17
CX04	+	0.60	0.14*	0.22
CX05	+	0.60	0.14*	0.42
CX06	+	0.60	0.14*	0.48
CX07	1.524	1.431	0.40	0.36
CX09	1.524	1.431	0.40	0.46
CX10	1.524	1.036	0.40	0.49
CX17	+	3.568	0.73*	0.66
CX23	+	0.792	0.21*	0.22
CX27	1.524	1.673	0.40	0.52
CX52	+	2.509	0.60*	0.64

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
CX01	0.06	0	+	+	+	+	0	0
03	0.05	0	+	+	+	+	0	0
04	0.02	-0.05	+	+	+	+	0	0
05	0.06	-0.01	+	+	+	+	0	0
06	0.07	-0.05	+	+	+	+	0	0
07	-0.01	-0.10	0.11	0	-0.12	-0.10	-0.01	0.10
09	-0.02	-0.10	0.11	0	-0.13	-0.10	-0.01	0.10
10	-0.11	-0.17	0	0.01	-0.11	-0.18	-0.01	0.10
17	-0.08	-0.24	-0.03	-0.02	-0.05	-0.22	-0.09	0.02
23	0.03	-0.02	+	+	+	+	0	0
27	-0.11	-0.23	0.01	0	-0.12	+0.23	-0.01	0.01
52	-0.08	-0.19	0.02	0.02	-0.10	-0.21	-0.09	0.02
Averages	-0.068	-0.172	0.037	0.002	-0.105	-0.173	-0.018	0.007

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
CX01	-0.03	-0.05	+	+	+	+
CX03	-0.04	-0.05	+	+	+	+
CX04	-0.04	-0.07	+	+	+	+
CX05	-0.08	-0.04	+	+	+	+
CX06	-0.09	-0.09	+	+	+	+
CX07	-0.09	-0.15	0	0	-0.09	-0.15
CX09	-0.08	-0.15	0	0	-0.08	-0.15
CX10	-0.04	-0.13	-0.01	-0.01	-0.03	-0.12
CX17	-0.18	-0.29	0.03	0.04	-0.21	-0.33
CX23	-0.06	-0.10	+	+	+	+
CX27	-0.06	-0.19	-0.03	-0.03	-0.03	-0.16
CX52	-0.14	-0.27	0.05	0.04	-0.19	-0.31
Averages	-0.098	-0.197	0.007	0.0[illegible]7	-0.105	-0.203

* Based on pre-mission test data at flight data calculated dose.
\+ No data available.

Evaluation of post-flight exposure data showed an effective reduction of film sensitivity of up to 1 f stop at the densities evaluated. This was also attributed to the change in maximum density caused by space radiation. No consistent effects were observed from the temperature/humidity effects data.

4.20.2 Comparison of Flight to Test Data, SO-368

Comparison of Pre-mission Dose Prediction and Flight Data Calculated Dose (Table 4-20a) showed the pre-mission prediction was within 10% of the flight data calculated value for 3 out of 4 rolls. Preflight predictions of changes in maximum density were less than actual flight values by an average of 0.08 density units. Test data comparison of maximum density changes based on flight data calculated doses were also in good agreement with flight data values except for roll CX05 and CX06. The calculated dose for these rolls was obviously in error.

Comparison of Houston Temperature/Humidity Effects to the similar effect from pre-mission test data showed general consistency but several random discrepancies were present.

4.21 Performance Evaluation, Film Type SO-168

Kodak Ektachrome EF Film, Type SO-168, was a high speed color reversal film used primarily for documenting crew and other operational activity within the Skylab. In addition to the operational photography, this film was used in support of Skylab Experiments S191, T013, T020, T053, M479, M487, M509, M516, M151, and for Student Investigations and Science Demonstrations. Most of this film was packaged in 400-ft or 140-ft cartridges for use in Skylab 16-mm Data Acquisition Cameras, One hundred 16-mm rolls were launched during the Skylab missions and 91 returned. In addition, 28 35-mm by 9-ft rolls of SO-168 film were launched for use in Skylab Nikon Cameras. Twenty-seven of these were used and returned.

Insofar as could be determined, this film was adequate to accomplish the requirements of the many experiments and applications in which it was used. However, some investigators identified a desire for color film with higher film speed than SO-168. It was noted that certain phenomena observed by the Skylab crew could not be photographed due to their low light levels and constrasts.

4.21.1 Environmental Analysis Results, SO-168

Although many rolls of SO-168 film were used on Skylab, complete sensitometric data, including Flight Pre and Post, Houston Pre and Post and Control sensitometry were available for only one roll. Therefore,

C-2

environmental effects analysis was based on the available sensitometry from rolls CL01, CI44, CI68, CI88 and CI89. Environmental timelines and H & D curves for these rolls are given in Appendix D, Figures D-103 through D-107. Numerical analysis results for reduction of maximum density, and changes in latent image and sensitivity at 0.6 and 1.2 below maximum density are given in Table 4-21.

TABLE 4-21. ANALYSIS RESULTS, FILM TYPE SO-168 (VISUAL)

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
CL01	+	1.193	0.76*	0.64
CI44	3.435	3.179	1.71	1.31
CI68	2.880	3.153	1.56	1.20
CI88	+	4.728	1.93*	1.76
CI89	+	4.726	1.93*	1.67

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
CL01	-0.19	-0.32	+	+	+	+	-0.07	-0.07
CI44	-0.46	-0.68	-0.06	-0.02	-0.40	-0.66	-0.16	-0.16
CI68	-0.41	-0.65	-0.02	-0.03	-0.39	-0.62	-0.16	-0.16
CI88	-0.73	-1.28	+	+	+	+	-0.32	-0.32
CI89	-0.71	-1.09	+	+	+	+	-0.32	-0.32

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
CL01	-0.26	-0.64	+	+	+	+
CI44	+	+	-0.02	0	+	+
CI68	-0.43	-0.70	0.01	0.03	-0.44	-0.73
CI88	+	+	+	+	+	+
CI89	+	+	+	+	+	+

\+ No data available
* Base on test data at Flight Data Calculated Dose

Decrease in maximum density values ranged from 0.64 to 1.76 density for the rolls evaluated. This caused a reduction in density range due to the effects of space radiation of over 50% for film rolls launched on SL1 and returned on SL4.

This caused a similar loss in contrast, effective image loss to pre-exposed sensitometry of up to 4 f stops at 1.2 density below max D, and effective loss in film sensitivity of up to 2 1/3 f stops. Although the effective image losses at the density values evaluated was very large, the threshold of detection was reduced by only 1 to 2 f stops. Therefore, little information was totally lost but considerable reductions in film contrast were experienced, particularly for faint objects.

Comparison of Flight and Houston Control sensitometry indicated that the effects of temperature/humidity were negligible; therefore, virtually all degradation of this film was caused by ionizing space radiation.

4.21.2 Comparison of Flight to Test Data, SO-168

Pre-mission radiation dose predictions, listed in Table 4-21a, were available for only two SO-168 rolls. Pre-mission predicted values for these rolls were within 10% of the Flight Data Calculated Dose. Pre-mission predictions for reduction in film maximum density were higher than measured values by 10 to 30%. Test data for this comparison was based on CO^{60} gamma ray exposures. Therefore, approximately 10% of this difference was due to the difference in energy spectra between the space radiation and the test radiation. Based on this information, the test and flight data were considered to be in good agreement.

Comparison of pre-mission latent image temperature/humidity test data and the Houston Control temperature/humidity data (Table 4-21b) showed poor agreement. Values from pre-mission test data were approximately ½ f stop larger than those derived from the Houston Control data.

4.22 Performance Evaluation, Film Type 2443

Kodak Aerochrome Infrared Film, Type 2443 was a false color infrared sensitive color reversal film with a 4 mil ESTAR base. This film was used on Skylab Experiments S063 and S190A and in operational hand-held Nikon Cameras. This film was used on S063 to photograph the Earth's twilight airglow, aurorae, red areas and noctilucent clouds. In the S190A, Multi-spectral Photographic Camera, it was used in camera station 3 to provide false color imagery of the Earth's surface in the spectral range of 500 to 880 nm. Eight 35-mm by 7-ft rolls we used for the S063 and operational

photography while 15 70-mm by 110-ft rolls were used in S190A. Two additional 70-mm rolls were launched on SL1 but were not used due to potential film degradation from the high SL1 temperatures. Sensitometric data for this film were available for only the S190A rolls. These rolls are listed below with the mission on which they were used.

Roll Number	Skylab Mission
03, 09, 15	SL2
21, 27, 33, 39, 45	SL3
51*, 57, 63, 69, 75, A3, B3	SL4

*Exposed with the camera filter not installed.

The 2443 film performed the requirements of the S190A Camera and the operational photography adequately. However, S190A camera station 3 was resolution limited by the film. No information was obtained concerning the adequacy of this film in fulfilling the requirements of the S063 experiment.

4.22.1 Environmental Analysis Results, 2443

Analysis of the environmental effect on this film were limited to film rolls used for S190A since no sensitometric exposures were made on the 35-mm rolls. The analysis was based on film rolls 03, 15, 21, 45, 57 and B3 which provide 2 rolls for each Skylab mission. H & D curves and environmental timelines for these rolls are given in Appendix D, Figures D-108 through D-113. Numerical analysis results are tabulated in Table 4-22 for the visual, red, blue and green data to provide intercomparison of environmental effects on the three emulsion layers.

The effects of ionizing radiation on the film maximum density are given in Table 4-22a. This table shows the reduction in maximum density for the visual, red and green filter measurements were approximately the same for each given roll. The blue filter readings were off scale. The reductions in maximum density due to radiation caused only a minimal effect that was essentially unobservable on the ground imagery. A variation of Flight Data Calculated Dose with the Actual Decrease in Maximum Density was observed by roll 3 was compared to roll 15. This variation was due to the inaccuracy of the calculated dose. In spite of this inaccuracy the pre-mission dose prediction and that calculated from flight data agreed very well. In each case, the dose predicted before the mission was only 3 to 10% higher than the flight data calculation.

Evaluation of the environmental effects on the latent image (Table 4-22b) showed negligibly small changes in the latent image for all rolls

TABLE 4-22. ANALYSIS RESULTS, FILM TYPE 2443

a. RADIATION DATA COMPARISON

	ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
VISUAL	3	0.552	0.472	0.12	0
	15	0.555	0.463	0.12	0.06
	21	1.038	0.990	0.38	0.23
	45	1.021	0.944	0.38	0.22
	57	+	1.550	+	0.33
	B3	+	1.905	+	0.40
RED	3	0.568	0.472	0.18	0.02
	15	0.571	0.463	0.18	0.10
	21	1.063	0.998	0.50	0.21
	45	1.045	0.944	0.49	0.22
	57	+	1.550	+	0.28
	B3	+	1.905	+	0.34
BLUE	3	0.564	0.472	0.14	Density Reading Off Scale
	15	0.566	0.463	0.14	
	21	1.213	0.998	0.97	
	45	1.192	0.944	0.96	
	57	+	1.550	+	
	B3	+	1.905	+	
GREEN	3	0.651	0.472	0.46	-0.03
	15	0.654	0.463	0.46	0.26
	21	1.063	0.998	0.35	0.22
	45	1.046	0.944	0.35	0.23
	57	+	1.550	+	0.22
	B3	+	1.905	+	0.44

b. LATENT IMAGE EFFECTS

	ROLL NUMBER	DELTA LOG EXPOSURE							
		FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON* TEST CONTROL-TEST PRE AT DENSITY:	
		0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
VISUAL	03	-0.02	-0.01	-0.05	-0.03	0.03	0.02	0.06	0.07
	15	0	0	-0.02	-0.01	0.02	0.01	0.06	0.07
	21	-0.03	-0.05	-0.02	-0.03	-0.01	-0.02	0.07	0.07
	45	-0.02	-0.05	-0.03	-0.04	0.01	-0.01	0.07	0.07
	57	-0.01	-0.03	-0.05	-0.01	0.06	-0.02	0.07	0.07
	B3	-0.08	-0.07	-0.03	-0.02	-0.05	-0.05	0.07	0.07
	Average	-0.027	-0.035	-0.033	-0.023	0.01	-0.012	0.067	0.07
RED	03	0	0.01	-0.02	-0.01	0.02	0.02	0.04	0.04
	15	0.01	0.02	0	0.01	0.01	0.01	0.04	0.04
	21	-0.06	-0.06	-0.04	-0.04	-0.02	-0.02	0.07	0.09
	45	-0.02	-0.04	-0.11	-0.15	0.09	0.11	0.07	0.08
	57	-0.02	-0.04	-0.02	-0.02	0	-0.02	0.05	0.06
	B3	-0.03	-0.07	-0.01	-0.01	-0.02	-0.06	0.05	0.06
	Average	-0.02	-0.03	-0.033	-0.037	0.013	0.007	0.053	0.06
BLUE	03	-0.06	-0.03	-0.09	-0.06	0.03	0.03	-0.16	-0.15
	15	-0.06	-0.04	-0.10	-0.06	0.04	0.02	-0.16	-0.15
	21	0.03	0.01	-0.04	-0.03	0.07	0.04	0.12	0.13
	45	0.02	0.01	-0.04	-0.02	0.06	0.03	0.12	0.13
	57	0.09	0.07	-0.03	-0.01	0.12	0.08	0.02	0.04
	B3	0.14	0.10	0.03	0.04	0.11	0.06	0.02	0.04
	Average	0.027	0.02	-0.045	-0.023	0.072	0.043	-0.007	0.007
GREEN	03	-0.01	0	-0.05	-0.03	0.04	0.03	-0.04	0.08
	15	-0.09	-0.02	-0.03	-0.01	-0.06	-0.01	-0.04	0.08
	21	-0.02	-0.04	-0.02	-0.02	0	-0.02	0.05	0.09
	45	-0.04	-0.01	-0.04	0.02	0	-0.03	0.05	0.09
	57	-0.04	-0.07	-0.02	-0.01	-0.02	-0.06	0.05	0.09
	B3	0	-0.05	0.02	0.03	-0.02	-0.08	0.05	0.09
	Average	-0.033	-0.032	-0.023	-0.003	-0.01	-0.028	0.02	0.087

c. FILM SENSITIVITY EFFECTS

	ROLL NUMBER	DELTA LOG EXPOSURE					
		FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
		0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
VISUAL	03	-0.06	-0.08	-0.03	-0.05	-0.01	-0.03
	15	-0.04	-0.07	0	-0.01	-0.04	-0.06
	21	-0.05	-0.13	-0.05	-0.05	-0.03	-0.08
	45	-0.05	-0.13	-0.03	-0.07	-0.02	-0.06
	57	-0.03	-0.11	-0.02	-0.05	-0.01	-0.03
	B3	-0.14	-0.23	-0.14	-0.19	0	-0.04
	Average	-0.062	-0.125	-0.048	-0.07	-0.018	-0.05
RED	03	-0.13	-0.14	-0.06	-0.06	-0.07	-0.08
	15	-0.10	-0.12	-0.06	-0.08	-0.04	-0.04
	21	-0.25	-0.29	-0.11	-0.15	-0.14	-0.14
	45	-0.24	-0.35	-0.22	-0.37	-0.02	0.02
	57	-0.26	-0.32	-0.23	-0.26	-0.03	-0.06
	B3	-0.27	-0.36	-0.28	-0.29	0.01	-0.07
	Average	-0.208	-0.263	-0.16	-0.202	-0.048	-0.062
BLUE	03	0.01	0.03	-0.02	0.01	0.03	0.02
	15	0.03	0.04	-0.02	0	0.05	0.04
	21	0.08	0.06	0	0.01	0.08	0.05
	45	0.08	0.07	0	0	0.08	0.07
	57	0.14	0.10	0.04	0.04	0.10	0.06
	B3	0.16	0.10	0.05	0.03	0.11	0.07
	Average	0.083	0.067	0.008	0.015	0.075	0.032
GREEN	03	0.07	-0.02	0.06	0	0.01	-0.02
	15	0.11	0	0.06	-0.02	0.05	0.02
	21	0	-0.05	0.01	0	-0.01	-0.05
	45	-0.01	-0.03	0	0.05	-0.01	-0.06
	57	-0.03	-0.09	0	-0.03	-0.03	-0.06
	B3	-0.01	-0.07	0.01	-0.03	-0.02	-0.04
	Average	0.022	-0.043	0.023	-0.008	-0.002	-0.035

+ No data available

but B3. It was noted that the red and green filter data showed a consistent latent image loss while the blue filter data showed an apparent image increase for film used on SL3 and SL4. These effects were small and therefore should have caused no observable color shift.

Evaluation of changes in film sensitivity showed more dynamic effects on the separate emulsion layers. As an example, roll B3 showed a loss in sensitivity of approximately 1 f stop for the red filter data while the blue filter data showed an increase in sensitivity of approximately ½ f stop. The change in the green layer was not significant. Evaluation of the separate effects of temperature/humidity and radiation showed most of the sensitivity loss in the red filter data was caused by temperature/humidity effects. The blue and green data, on the other hand, showed virtually no change due to this environmental parameters. These data suggest that color shifts in this film, although not directly observed may have been present on exposures made near the latter part of the SL3 and SL4 mission due to the sensitivity changes described above.

4.22.2 Comparison of Flight and Test Data, 2443

Comparative data given in Table 4-22a and 4-22b show that, in general, the flight and test data for this film do not compare well. This relatively poor comparison was attributed to the difference between the test film and the flight film. Pre-mission tests were performed using Ektachrome Infrared Film, Type SO-180 while Aerochrome Infrared Film, Type 2443 was finally selected for use on Skylab.

4.23 <u>Performance Evaluation, Film Type 3443</u>

Film Type 3443 was the same emulsion as type 2443 but was provided on 2.5 mil ESTAR base. This film was used on Skylab Experiments M479 and S190B. Experiment M479, Zero Gravity Flammability used one 400-ft roll of 3443 in a 16-mm Data Acquisition Camera to photograph the ignition, propagation and extinguishment characteristics of materials in zero gravity. Although acceptable data was collected to fulfill the experiment requirements both a higher speed film and camera were desired and recommended to provide a higher frame rate for observing this rapidly changing phenomenon.

Experiment S190B, Earth Terrain Camera, also used only one roll of 3443. This roll contained 5-in. by 210-ft film and was used on the SL3 mission. A similar roll of this type of film was launched on SL1 but was not used due to suspected environmental degradation and operating time limitations on the S190B camera. The 3443 film roll used in S190B showed random blue streaking 1 to 2 mm wide which were attributed to an

emulsion defect. In spite of this anomaly, good imagery was obtained. The comparatively low resolution of this film defined the resolution limit for the color infrared S190B photography. Therefore, to obtain higher resolution imagery, Kodak High Definition Aerochrome Infrared Film, Type SO-131 was used in place of 3443 on the SL4 mission.

4.23.1 Environmental Analysis Results, 3443

Sensitometric data for this film was available for only the S190B roll 87. H & D curves and the environmental timeline for this roll are given in Appendix D, Figure D-114. Numerical analysis results, based on the H & D curves for each of the four densitometer filters are given in Table 4.23. These data showed environmental effects similar to those

TABLE 4-23. ANALYSIS RESULTS, FILM TYPE 3443

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
87				
Visual	1.02	.95	.38 (.21)*	.18
Red	1.05	.95	.49 (.20)*	.22
Green	1.05	.95	.96 (.05)*	.17
Blue	1.19	.95	.35 (.28)*	**

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
87								
Visual	-.03	-.03	-.02	-.01	-.01	-.02	.07	.05
Red	-.03	-.03	-.01	-.01	-.02	-.02	.05	.07
Green	-.04	-.04	-.04	-.02	0	-.02	.06	.09
Blue	**	**	**	**	**	**	**	**

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
87						
Visual	.02	-.02	.03	.04	-.01	-.06
Red	-.07	-.09	.02	.03	-.09	-.12
Green	.02	0	.03	.04	-.01	-.04
Blue	**	**	**	**	**	**

+ No Data Available
* Based on pre-mission test data using Flight Calculated Dose
** Readings off scale of Densitometer

observed for film type 2443. The Pre-mission Radiation Dose Prediction wa 7 to 24% higher than that calculated using flight data and the Actual Decrease in Maximum Density was much less than that predicted by pre-mission testing of film type SO-180. Both latent image and film sensitivity effect were negligible and comparison of the 3443 latent image effects and those derived from SO-180 pre-mission test data showed these two film types responded differently to similar environmental storage conditions.

4.24 Performance Evaluation, Film Type SO-131

Kodak High Definition Aerochrome Infrared Film, Type SO-131 was a newly developed false color infrared sensitive reversal film with higher resolution and lower film speed than 3443. This film was used during SL4 as a replacement for film type 3443 to obtain higher resolution photography from the Skylab Earth Terrain Camera, Experiment S190B. The film performed very well resulting in high quality imagery of the Earth. However, the S190B camera was still resolution limited by the film. The single 5-in by 210-ft roll used was designated as S190B roll 93.

4.24.1 Environmental Analysis Results, SO-131

The environmental timeline and H & D curves for roll 93 are given in Appendix D, Figure D-115. Numerical analysis results based on the H & D curves are given in Table 4-24. Since this film was a new Kodak product, no comparative pre-mission test data were available. The reduction in maximum density for the Flight Data Calculated Radiation Dose was approximately the same as that observed for a similar dose on the film type 2443. This implies equivalent sensitivity to ionizing space radiation but was based on an extremely small sample of only one roll.

Latent image effects for roll 93 showed total effective latent image loss of ¼ f stop; the blue curve showed the largest affect. The relative effects of the separate environmental parameters were not conclusive due to the small sample of data available. It was, however, noted that the Houston Control showed a reduction in maximum density similar to that experienced by the flight film. Therefore, a separation of environmental parameter effects would have had a high uncertainty and, therefore, was not attempted.

Film sensitivity effects data showed less sensitivity change than that observed on the 2443 film flown on SL4. A basic difference in SO-131 and 2443 was noted in the response of the data measured with the blue densitometer filter. SO-131 showed a small sensitivity loss in this layer while film type 2443 showed an apparent increase in sensitivity.

TABLE 4-24. ANALYSIS RESULTS, FILM TYPE SO-131

a. RADIATION DATA COMPARISON

ROLL NUMBER	PRE-MISSION DOSE PREDICTION (Rads Air, Co^{60})	FLIGHT DATA CALCULATED DOSE (Rads Air, Space Radiation)	PRE-MISSION PREDICTED DECREASE IN MAXIMUM DENSITY (Film Density)	ACTUAL DECREASE IN MAXIMUM DENSITY (Film Density)
93				
Visual	+	1.47	+	.24
Red	+	1.47	+	.29
Green	+	1.47	+	.09
Blue	+	1.47	+	.17

b. LATENT IMAGE EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE							
	FLIGHT FILM DATA CONTROL-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON PRE AT DENSITY:		RADIATION EFFECT HOUSTON PRE-FLIGHT PRE AT DENSITY:		TEMPERATURE/HUMIDITY TEST DATA COMPARISON TEST CONTROL-TEST PRE AT DENSITY:	
	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D	0.6 BELOW MAX. D	1.2 BELOW MAX. D
93								
Visual	-.09	-.11	-.02	-.03	-.07	-.08	+	+
Red	-.03	-.08	.03	.01	-.06	-.09	+	+
Green	-.01	.08	.01	.07	-.02	.01	+	+
Blue	-.13	-.16	-.09	-.15	-.04	-.01	+	+

c. FILM SENSITIVITY EFFECTS

ROLL NUMBER	DELTA LOG EXPOSURE					
	FLIGHT FILM CONTROL-FLIGHT POST AT DENSITY:		TEMPERATURE/HUMIDITY EFFECT CONTROL-HOUSTON POST AT DENSITY:		RADIATION EFFECT HOUSTON POST-FLIGHT POST AT DENSITY:	
	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY	0.6 BELOW MAX DENSITY	1.2 BELOW MAX DENSITY
93						
Visual	.06	-.10	-.01	-.02	.07	-.08
Red	-.06	-.11	.03	.02	-.09	-.13
Green	.01	.07	.02	.09	-.01	-.02
Blue	-.09	-.10	-.08	-.09	-.01	-.01

+ No data available.

5. CONCLUSIONS

Evaluation of the Skylab environmental effects on the photographic film used on Skylab has provided an unprecedented insight into the use of film for space borne applications. The results of this evaluation demonstrate that photographic film was both adequate and in most cases the best available detection and recording system for the many applications to which it was applied. Within the limits of the film design capability all but one Skylab experiment, that used photographic film, successfully recorded the data of interest and met the experiment's scientific requirements. Problems which resulted in total loss of data or unacceptable degradation of photographic data were, generally, due to anomalies in camera or hardware operation and not to environmental film degradation. In addition, it was determined that data interpretation and analysis could be accomplished with even higher levels of environmental degradation than originally defined, provided suitable film calibration data were generated.

General conclusions derived from this environmental effect study are given below as they relate to the Skylab environment, environmental effects on photographic film and film related problems. Specific conclusions for each film type are given in Section 4.

Skylab Environments

- The Vette radiation models were, generally, adequate to define the external spacecraft radiation environment but generalizations and approximations made in simulation usage schedules, usage locations and spacecraft approximations used in shielding calculations produced errors of up to a factor of two.

- On the average, the proton flux measured during the Skylab was about 80% of the flux predicted by the AP7 Vette radiation model for protons above 50 MeV.

- On-board radiation measurements indicated a higher energy proton spectrum at a lower altitude than the Vette model used for Skylab calculations.

- Film vaults provided to shield the film from ionizing radiation were adequate and no films were fogged beyond their usefulness by ionizing radiation.

- The normal Skylab internal environment during the manned phases was an acceptable storage environment for most photographic films. However, an atmosphere, void of free oxygen, would have minimized film degradation of most types of film.

Environmental Effect on Photographic Film

- Environmental effects on Skylab photographic films were observable on almost every type of film but did not produce film degradation to the extent that experiment data recording and analysis requirements could not be met.

- Environmental effects on photographic film must be considered independently for each type of film or photographic emulsion. Application of environmental effects data of one film type to another showed disagreement in almost every case.

- Although the environmental effects on latent image fading and film sensitivity due to storage time, temperature and relative humidity were separated from ionizing radiation effects using Houston Control data; this could not be done with any certainty for film fogging due to apparent changes in film sensitivity to ionizing radiation as a function of temperature. Therefore, some variance in relating film fogging to radiation levels was assumed to be due to unknown contributions of temperature effects.

- The high OWS temperatures experienced during SL1 and SL2 due to the loss of the meteoroid shield increased the level of film degradation but photographic data recorded with several types of film that experienced these high temperatures was still usable. However, a need for more film calibration data to account for film degradation during data analysis was defined.

- The most universally expressed short coming associated with the use of film on Skylab scientific experiments was a need for more and better film calibration and sensitometric data.

Film Related Problems and Anomalies

- Evaluation of the Skylab environmental effects on the vacuum-ultraviolet sensitive Schumann type emulsion films resulted in the compilation of several anomalies associated with these films. For the most part, these anomalies, as listed below, are unsolved and should be investigated.

  1. Latent Image Fading - Severe latent image fading was encountered on film type SC-5. This resulted in a major loss of scientific data.

  2. Loss of Film Sensitivity - Film type SC-5 showed an unacceptable loss of sensitivity, reducing the detection efficiency significantly.

3. Chemical Fogging - Film type 101-05 was repeatedly fogged beyond use by unknown sources. The fogging was attributed to chemical reactions but the fogging agents were not isolated.

4. Loss of Maximum Density - Film types 104-06 and 101-06 suffered a reduction in the maximum density and thus reduced the density range and contrast of the film.

5. Film Holder Image Anomalies - Film types 104-06, 101-05 and 101-06 showed images or desentization in areas adjacent to ribbing and hole patterns in stainless steel film holders. This caused film density variations and complicated the film data analysis.

The combined effects of items 1, 2 and 3 resulted in an almost total loss of data for the Experiment S183 spectrophotometric camera.

- Many phenomena investigated by Skylab photographic experiments were low light level objects. Therefore, long exposure times were required which gave rise to film reciprocity failure. This became a problem on some experiments because film calibration data did not adequately consider the effects of reciprocity.

- One Skylab experiment experienced reticulation of the flight film due to a distilled water wash between the developer and fix. This was eliminated by using SB5 stop bath in place of the distilled water. It was concluded that, although distilled water pre-baths are used to reduce fog levels on some films, a distilled water wash between chemicals and after processing is not recommended.

- Other problems observed that caused minimal effects on Skylab film data evaluation were electrostatic fog and marks, film cleanliness, emulsion cracking, abrasion of unovercoated film, and color film dye instability.

6. RECOMMENDATIONS

Recommendations given in this section are directed toward obtaining improved detection, recording and analysis results with photographic films on future space borne payloads. The primary source of these recommendations was the Skylab experiments Principal Investigators. Therefore, they were based on the Principal Investigator's experience in testing, using and analyzing the Skylab film data in their individual areas of scientific application. Due to the unique nature of many of these areas, Principal Investigator's recommendations were usually applicable to only the film type or spectral region specified. Additional recommendations were provided by the Skylab film environmental analysis team who prepared this report.

Based on these inputs the following recommendations are made:

- Schumann type films should be evaluated and tested to solve or correct the five problems described for these films in Section 5.

- Since the presence of free oxygen in the atmosphere appeared to accelerate latent image fading and sensitivity changes; testing of the effects of air, N_2 and inert atmospheres on these parameters are recommended to define optimum atmospheres to minimize film degradation due to storage environments.

- Future scientific applications of film in space are expected to require better radiometric accuracy and therefore better and more precise film calibration. Additional effort in film calibration for space applications are recommended in the following areas:

  1) Utilization of current state-of-the-art techniques.
  2) Calibration in the spectral bands of application.
  3) Development of calibration sensitometers for soft x-ray and XUV radiation.
  4) Development of flight sensitometers or other capability to obtain accurate in-flight film calibration data.
  5) Calibration and pre-flight tests for reciprocity failure.
  6) Spectral sensitivity calibration of soft x-ray, XUV and UV sensitive flight and test films.

- Skylab Experiment S056, X-ray Telescope utilized one roll of color film to investigate color film as a spectrally sensitive detector for X-ray astronomy. This roll gave inconclusive data due to a lack of laboratory calibration data. It is recommended that additional laboratory testing be performed to support analysis of the Skylab data and provide baseline data for future X-ray astronomy systems.

- Several Skylab film related problems were associated with camera operation in the vacuum of space. Therefore, it is recommended the flight cameras be subjected to flight configuration environmental testing before launch with flight film and simulated targets. This will identify both camera operational and film environmental problems such as electrostatic discharge, emulsion cracking, film scratching and reciprocity failure.

- Uncertainty in the film ionizing radiation dose due to the lack of dose measurements reduced the accuracy and dependability of the Skylab film radiation data. Future space born film cassette designs should provide for small, light weight, removable passive dosimeters which would directly record radiation dose data for each film roll. Such data would be valuable for both pre- and post-processing applications.

- Preliminary film processing optimization tests of film irradiated with ionizing radiation have shown that enhancement of visual imagery over radiation fogging may be possible by optimization of developer time and temperature for particular radiation levels. It is recommended that this be investigated further.

- The dates on which sensitometric exposures were applied to Skylab flight and test film were critical to the environmental effects analysis. Recording, storing and recovering these dates for data users is a time consuming record keeping process. The addition of a date block exposure applied to the film simultaneously with the sensitometric exposure would greatly simplify this process for both the film lab and the user. It is recommended that such a date block be added to both new and existing sensitometers.

- Skylab pre-mission tests considered the latent image fading and film fogging. Skylab flight film provided data on film sensitivity change due to spacecraft storage and the combined environmental effect. Therefore, film sensitivity and combined environmental effects data are not available for some films that have a high probability of future use in space. It is recommended that laboratory film tests be performed to fill the voids in this data as future experiment candidate films are defined.

- Several scientific investigators identified exposure accuracy problems, particularly in photographic objects with variable light intensities. Therefore, it is recommended that an automatic exposure control feature be added to selected 16 mm cameras to reduce the loss of data due to over and under exposure.

- The potential for future long term space missions and the desirability of photographic film data recording suggest inflight processing as a means of controlling environmental film degradation. Therefore, investigations in this area are recommended.

- Color film dye fading was observed and defined to be a problem in the analysis of Experiment S056 data. Although this is not a newly identified phenomenon, the impact of color fading on space born experiment photographic data should be assessed as a part of the film selection process.

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s. Martin Marietta Corp., MDA Module Report, SL3, Volume II, ED-2002-1702, November 1973

t. Martin Marietta Corp., MDA Module Report, SL4, Volume III, ED-2002-1702, April 1974

u. V. Pizzo and J. T. Gosling; A Sensitometer Box for Solar Corona Photometry, AAS Photo-Bulletin, 1, 1972, 19.

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c. M. Weinstein, Skylab III (4) Sensitometric Summary, Johnson Space Center, TR-74-2, June 1974

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e. SL/3 Sensitometry Data Package, Johnson Space Center, JL12-503, November 23, 1973

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6. Test Data Documents

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g. R. R. Adams; The Photographic Effects of Ionizing Radiation on 13 Skylab Candidate Film Types, Preliminary Data, NASA Langley Research Center, February 23, 1971

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APPROVAL

SKYLAB FILM ENVIRONMENTAL EFFECTS REPORT

BY

SKYLAB PROGRAM OFFICE

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Walter F. Gillespie
Technical Monitor

H. W. Strickland
Director, Logistics Office

APPENDIX A

SKYLAB FLIGHT FILM GENERAL DESCRIPTION

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APPENDIX

SKYLAB FLIGHT FILM GENERAL DESCRIPTION

Film Name and Type	Description	Skylab Experiment
Kodak Special Film, Type 088-03 (NTB3)	High sensitivity, NTB3 thin nuclear track emulsion, capable of recording charged particles. Emulsion thickness of 6 micrometers on 4 mil ESTAR base.	S201
Kodak Special Film Type 104-06	Shumann type emulsion for recording ultraviolet radiation below 220 nm, similar to Kodak Short Wavelength Radiation (SWR) emulsion but coated on 7 mil ESTAR base with anti-halation backing. 104-06 also has beaded edges which separate the convolutions on the film roll to prevent emulsion surface abrasion from film back to emulsion surface contact in rolls.	S082A & S082B
Kodak SC-5	Kodak-Pathe Schumann type emulsion coated on 35 mm by 40 mm glass plates.	S183
Kodak Special Film, Type 101-05	Schumann type emulsion for recording 5-400 nm radiation. Approximately 10 times faster than 104-06 or SWR. Coated on glass plates.	S183
Kodak Special Film, Type 101-06	Same emulsion as 101-05 but coated on 7 mil ESTAR base with beaded edges.	S019, S082A & S082B
Kodak Spectroscopic Film, Type 103a-0	Spectroscopic film for long exposure time, unmodified spectral sensitivity (250 to 500 nm)	S183

SKYLAB FLIGHT FILM GENERAL DESCRIPTION

Film Name and Type	Description	Skylab Experiment
Kodak Solar Flare Patrol Film (ESTAR-AH Thin Base) SO-101	Fine grain, high contrast, panchromatic emulsion with extended red sensitivity. Maximum sensitivity at H-alpha line, (6563 nm) 2.5 mil ESTAR Base with 0.1 density anti-halation dye and fast drying PX backing. Same as SO392 except for base.	H-alpha
Kodak High Definition Aerial Film (ESTAR Thin Base) 3414	Slow-speed, high definition emulsion with extended red sensitivity and very high resolution. 2.5 mil ESTAR base with dyed-gel backing.	S190B
Kodak Panatomic-X Aerial Film (ESTAR Thin Base) 3400	Intermediate-speed, high contrast, fine grain panchromatic emulsion with extended red sensitivity. Coated on 2.5 mil ESTAR base with dyed-gel backing.	T025*
Kodak Spectrographic XUV Film (ESTAR Thin Base) SO-212	Panchromatic emulsion with extended red sensitivity on 2.5 mil ESTAR base with Rem-Jet backing and no emulsion overcoat. Same emulsion as aerial type 3400. (Eastman Kodak discontinued this film, 12/74).	S054 & S056
Kodak Panatomic-X Aerial Film (ESTAR Base) SO-022	Same as aerial type 3400 but on 4.0 mil ESTAR base with dye gel backing (discontinued 3/75)	S190A

*Film was launched on Skylab but was not used nor returned.

SKYLAB FLIGHT FILM GENERAL DESCRIPTION

Film Name and Type	Description	Skylab Experiment
Kodak Special Film, Type 026-02	Same as aerial type 3400, but had modified reciprocity characteristics for long exposure time. 2.5 mil ESTAR base.	S052
Kodak Plus-X Aerial Film (ESTAR Thin Base 3401	Medium-speed, high contrast, fine grain panchromatic emulsion with extended red sensitivity and high acutance on 2.5 mil ESTAR base with dyed-gel backing.	S191 & S233
Kodak Tri-X Aerographic Film (ESTAR Base) 2403	High-speed panchromatic emulsion with extended red sensitivity on 4 mil ESTAR base with fast-drying backing.	T025*
Kodak Tri-X Recording Film (ESTAR Base) SO-265	Modified 2403 on 4 mil ESTAR base with Rem Jet backing; emulsion No. 101 which had soluble dark dye in the pelloid (discontinued 3/75).	T025 & S063
Kodak 2485 High Speed Recording Film (ESTAR-AH Base)	Extremely high speed panchromatic film with extended red sensitivity on 4 mil ESTAR-AH base with 0.1 density and fast drying PX backing	T027, S063, S073, & S232
Kodak Infrared AERO-GRAPHIC Film (ESTAR Base) 2424	High contrast emulsion, sensitive to infrared radiation and visible light on 4 mil ESTAR base with fast drying PX backing.	S190A

*Film was delivered to KSC but was not launched due to parasol deployment in the solar airlock. 2403 was replaced by SO-265 for SL4 operation.

SKYLAB FLIGHT FILM GENERAL DESCRIPTION

Film Name and Type	Description	Skylab Experiment
Kodak Aerial Color Film (ESTAR Thin Base) SO-242	Slow Speed, high resolution, extremely fine grain color-reversal film with high contrast and good color saturation on 2.5 mil ESTAR base with clear-gel backing.	S056 & S190B
Kodak High Definition EKTACHROME Film (ESTAR Base) SO356	Slow speed, extremely fine grain, high contrast color-reversal film with good color saturation. Same as SO-242, but on 4 mil ESTAR Base.	S190A
Kodak EKTACHROME MS Film (ESTAR Thin Base) SO-368	Medium speed, color reversal film, color balanced for daylight. 2.5 mil ESTAR base with fast drying PX backing.	T053, S063, S191 & Operational
Kodak EKTACHROME EF Film (ESTAR Thin Base) SO-168	High speed, color reversal film, color balanced for daylight. 2.5 mil ESTAR base with fast drying PX backing.	T013, T020, T053, S191, M151, M479, M487, M509, M516 & Operational
Kodak Aerochrome Infrared Film (ESTAR Base) 2443	"False color", infrared sensitized reversal film on 4 mil. ESTAR base with a fast drying backing.	S063, S190A
Kodak Aerochrome Infrared Film (ESTAR Thin Base) 3443	Same emulsion as 2443 but on 2.5 mil ESTAR base with a clear gel backing.	S190B, M479
Kodak High Definition Aerochrome Infrared Film (ESTAR Thin Base) SO-131	Low speed, high resolution, infrared color reversal film on 2.5 mil ESTAR base.	S190B

APPENDIX B

SKYLAB FILM APPLICATION SUMMARY

SKYLAB FILM APPLICATION SUMMARY

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
NTB3	S201 Far UV Electrographic Camera	Dr. T. Page NRL @ JSC	Study Kohoutek's emissions in wavelength bands of 105 - 160 nm and 123 - 160 nm, including emissions of atomic oxygen and hydrogen Lyman-alpha, using electrographic camera. Film recorded 25 Kv electron images.
104-06	S082A/S082B XUV Spectroheliograph/ Spectrograph	Dr. R. Tousey NRL	Spectroheliograms of solar disk in short XUV wavelengths covering 15 to 65 nm and line spectra of solar regions covering 97 to 394 nm.
SC-5	S183 UV Panorama	Dr. G. Courtes LAS, France	Photograph starfields in 60 nm bandwidths centered about 187.8 nm and 297 nm.
101-05	S183 UV Panorama	Dr. G. Courtes LAS, France	Photograph Kohoutek's emissions in 60 nm bandwidths centered about 187.8 nm and 297 nm.
101-06	S019 UV Stellar Astronomy	Dr. K. Henize JSC	Photograph stellar UV emission and absorption spectra covering 130 to 500 nm.

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
101-06 (continued)	S020 X-Ray/UV Solar Photography	Dr. R. Tousey NRL	Photograph X-ray/UV solar line spectra covering 1 to 20 nm.
103aO	S183 UV Panorama	Dr. G. Courtes LAS, France	16mm starfield photographs of 36 nm bandwidth centered at 256 nm. Also used in film carrousel on plates for photographs of 60 nm bandwidths centered about 187.8 nm 297 nm.
SO101	H-Alpha Solar Telescope	Dr. E. Reeves HCO	Photographic record of the ATM pointing history at 656 nm wavelength (H-alpha)
3414	S190B Earth Terrain Camera	K. Demel JSC	Earth resources photography extending from visible into near infrared with higher resolution than S190A.
SO212	S054 X-Ray Spectrographic Camera	Dr. A. Krieger AS&E	Photograph spatial and spectral distribution of X-ray emissions from the sun's lower corona in six wavelength bands from 0.2 to 6 nm.

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
S0212 (Continued)	S056 X-Ray Telescope	Dr. E. Tandberg-Hanssen MSFC Dr. J. Underwood Aerospace Corp.	Photograph the sun's lower corona in six wavelength bands from 0.6 to 3.3 nm.
S0022	S190A Multispectral Photography Facility	K. Demel JSC	Multispectral, radiometrically accurate photography of Earth's surface in visible light (500 to 600 nm and 600 to 700 nm).
026-02	S052 White Light Coronagraph	Dr. R. MacQueen HAO	Photographic data of the brightness, form, and polarization of the solar corona out to 6 solar radii in visible light.
3401	S191 Infrared Spectrometer	R. Juday JSC	Provide a visible wavelength photographic record of the IR spectrometer's ground track.
	233 Kohoutek Photometric Photography	Dr. C. Lundquist MSFC	Document the structure of the comet and calibrate its visible photometric brightness.

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
S0265	S063 UV Airglow Horizon Photography	Dr. D. Packer NRL	Photograph the Earth's ozone layer, twilight airglow, aurorae, red arcs, and noctilucent clouds in near UV and visible wavelength bands.
	T025 Coronagraph Contamination Measurement	Dr. M. Greenberg Dudley Observatory	Photograph reflected sunlight from Earth's upper atmospheric particles and Skylab's contamination cloud in near UV and visible wavelength bands.
2485	S063 UV Airglow Horizon Photography	Dr. D. Packer NRL	Photograph the Earth's ozone layer, twilight airglow, aurorae, red arcs, and noctilucent clouds in near UV and visible wavelength bands.
	S232 Barium Plasma Observations	D. E. Westcott U. Of Alaska	Photograph rocket-launched luminescent cloud of ionized barium particles as they align along the Earth's magnetic field lines.
	T027 Contamination Measurement	Dr. J. Muscari MMC	Provide a 16mm visible record of the photometer system pointing direction and photograph any bright contamination particles in field of view.

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
2485 (Continued)	S073 Gegenschein/Zodiacal Light	Dr. J. Weinberg SAL @ SUNYA	Provide 16mm visible record of photometer system pointing direction and photograph night sky. Also photograph Gegenschein, lunar libration regions, etc. in visible and near UV with 35mm camera.
2424	S190A Multispectral Photographic Facility	K. Demel JSC	Multispectral, radiometrically accurate photography of the Earth's surface in visible and near infrared (700 to 800 nm and 800 to 900 nm).
S0242	S190B Earth Terrain Camera	K. Demel JSC	Earth resources photography extending from visible into near infrared with higher resolution than S190A.
	S056 X-Ray Telescope	E. Tandberg-Hanssen MSFC J. Underwood Aerospace Corp.	Photograph the sun's lower corona in six wavelength bands from 0.6 to 3.3 nm of color film for this purpose was experimental.
S0356	S190A Multispectral Photographic Facility	K. Demel JSC	Multispectral color photography of the Earth's surface in visible light (400 to 700 nm).

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
SO368	Operational		Color exterior photography.
	S063 UV Airglow Horizon Photography	Dr. D. Packer NRL	Color photography of Earth's twilight airglow, aurorae, red arcs, and noctilucent clouds.
	S191 Infrared Spectrometer	R. Juday JSC	Provide a visible light photographic record of the IR spectrometer's ground track.
SO168	S191 Infrared Spectrometer	R. Juday JSC	Provide a visible light photographic record of the IR spectrometer's ground track.
	Interior Experiments and Operational		Interior color photography.
	M551 Metals Melting	R. Poorman MSFC	Photograph melting and re-solidification of metals in M512 chamber.
	M553 Sphere Forming	E. Hasemeyer MSFC	Photograph melting and re-solidification of metals in M512 chamber.

SKYLAB FILM APPLICATION SUMMARY
(continued)

FILM TYPE	EXPERIMENT	P.I.	OBJECTIVE
2443	S063 UV Airglow Horizon Photography	Dr. D. Packer NRL	Photograph Earth's twilight airglow, aurorae, red arcs, and noctilucent clouds.
	S190A Multispectral Photographic Facility	K. Demel JSC	Multispectral false color photography of the Earth's surface in visible and near infrared (500 to 880 nm)
	Operational		Earth and crew false color photography with hand held cameras.
3443	S190B Earth Terrain Camera	K. Demel JSC	Earth resources false color IR photography with higher resolution than S190A (500 to 880 nm).
	M479 Zero-Gravity Flammability	J. Kimsey JSC	Photograph the ignition, propagation and extinguishment characteristics during the combustion of various materials in the M512 chamber
SO131	S190B Earth Terrain Camera	K. Demel JSC	High resolution earth resources false color IR photography with higher resolution than film type 3443 (500 to 880 nm).

APPENDIX C

PRINCIPAL INVESTIGATORS/SCIENTISTS ADDRESSES

APPENDIX

PRINCIPAL INVESTIGATORS/SCIENTISTS ADDRESSES

Name/Address	Experiment
Dr. Georges Courtes Centre National d'Etudes Spatiale Laboratoire d'Astronomie Spatiale Marseilles, France	S183 - Ultraviolet Panorama
K. J. Demel Science and Applications Directorate Lyndon B. Johnson Space Center National Aeronautics and Space Administration Houston, Texas 77058	S190A - Multispectral Photographic Facility and S190B - Earth Terrain Camera
Dr. Mayo Greenberg The Dudley Observatory 100 Fuller Road Albany, N.Y. 12205	T025 - Coronagraph Contamination Measurement
Earl Hasemeyer Material and Processes Laboratory George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, Alabama 35812	M553 - Sphere Forming
Dr. Karl Henize Lyndon B. Johnson Space Center National Aeronautics and Space Administration Houston, Texas 77058	S019 - UV Stellar Astronomy
Richard Juday Lyndon B. Johnson Space Center National Aeronautics and Space Administration Houston, Texas 77058	S191 - Infrared Spectrometer

PRINCIPAL INVESTIGATORS/SCIENTISTS ADDRESSES
(Continued)

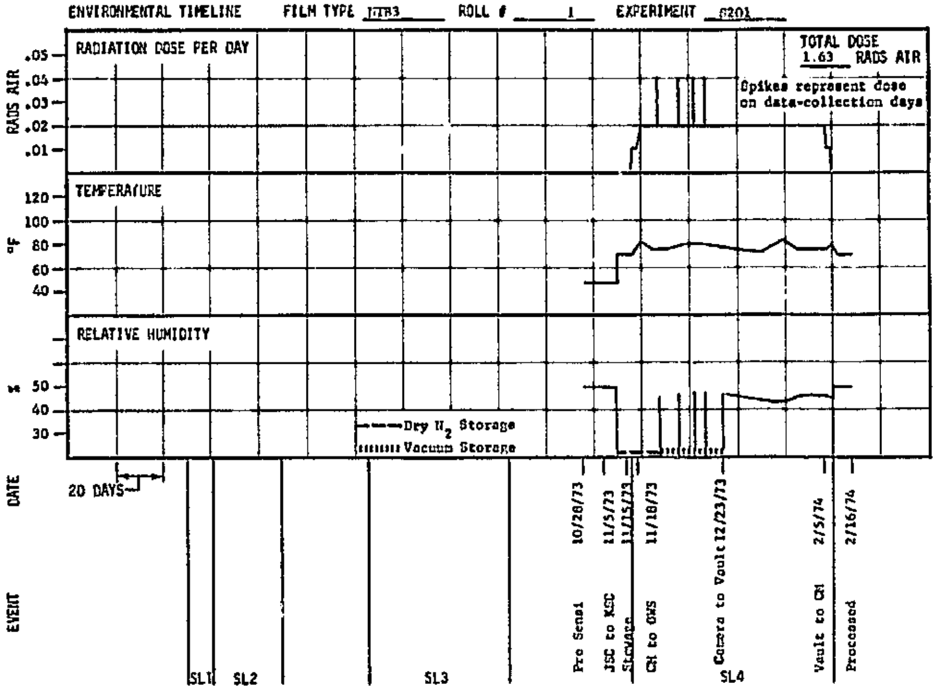
Name/Address	Experiment
J. Howard Kimsey Lyndon B. Johnson Space Center National Aeronautics and Space Administration Houston, Texas 77058	M479 - Zero-Gravity Flammability
Dr. A. Krieger American Science and Engineering, Inc 955 Massachusetts Avenue Cambridge, Massachusetts 02139	S054 - X-ray Spectrographic Camera
Dr. Charles Linquist Director Space Sciences Laboratory George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, Alabama 35812	S233 - Kohoutek Photometric Photography
Dr. Robert MacQueen High Altitude Observatory P. O. Box 3000 Boulder, Colorado 80302	S052 - White Light Coronagraph
Dr. Joseph Muscari Martin Marietta Aerospace P. O. Box 179 Denver, Colorado 80201	T027 - Contamination Measurement
Dr. Donald Packer Naval Research Laboratory Washington, D.C. 20375	S063 - UV Airglor Horizon Photography
Dr. Thornton Page Lyndon B. Johnson Space Center National Aeronautics and Space Administration Houston, Texas 77058	S201 - Far UV Electrographic Camera

PRINCIPAL INVESTIGATORS/SCIENTISTS ADDRESSES
(Continued)

Name/Address	Experiment
Richard Poorman Materials and Processes Laboratory George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	M551 - Metals Melting
Dr. Edward Reeves Harvard College Observatory 60 Garden Street Cambridge, Massachusetts 02138	H-Alpha Solar Telescope
Dr. E. Tandberg - Haussen Space Sciences Laboratory George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	S056 - X-ray Telescope
Dr. J. Underwood Aerospace Corporation P. O. Box 92957 Los Angeles, California 90009	S056 - X-ray Telescope
Dr. Richard Tousey Naval Research Laboratory Washington, D.C. 20375	S082A - XUV Spectroheliograph S082B - UV Spectrograph S020 - X-ray/UV Solar Photography
Dr. Jerry Weinberg Director, Space Astronomy Laboratory Executive Park E Stuyvesant Plaza Albany, New York 12203	S073 - Gegenschein/Zodiacal Light
Dr. Eugene Westcott University of Alaska Fairbanks, Alaska	S232 - Barium Plasma Observations

APPENDIX D

SKYLAB FILM DATA CURVES



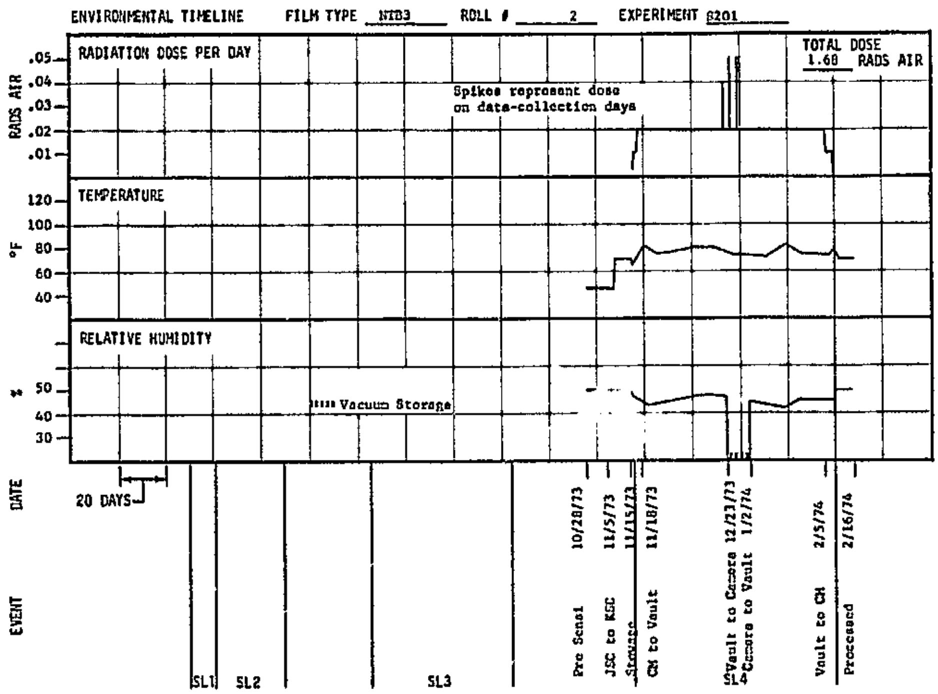


FIGURE D-1 ENVIRONMENTAL TIMELINES: FILM TYPE NTB3, ROLLS 1 & 2

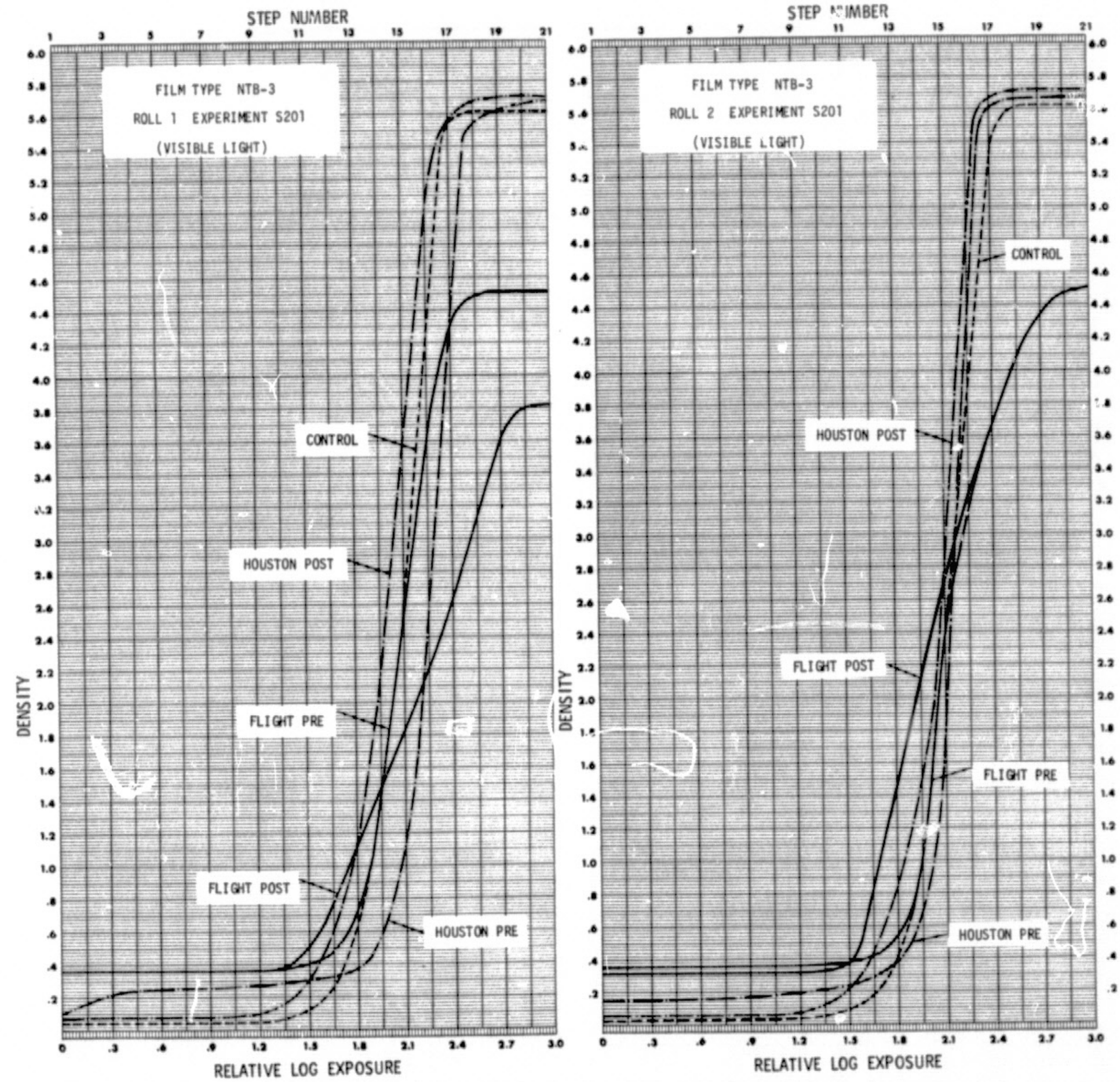
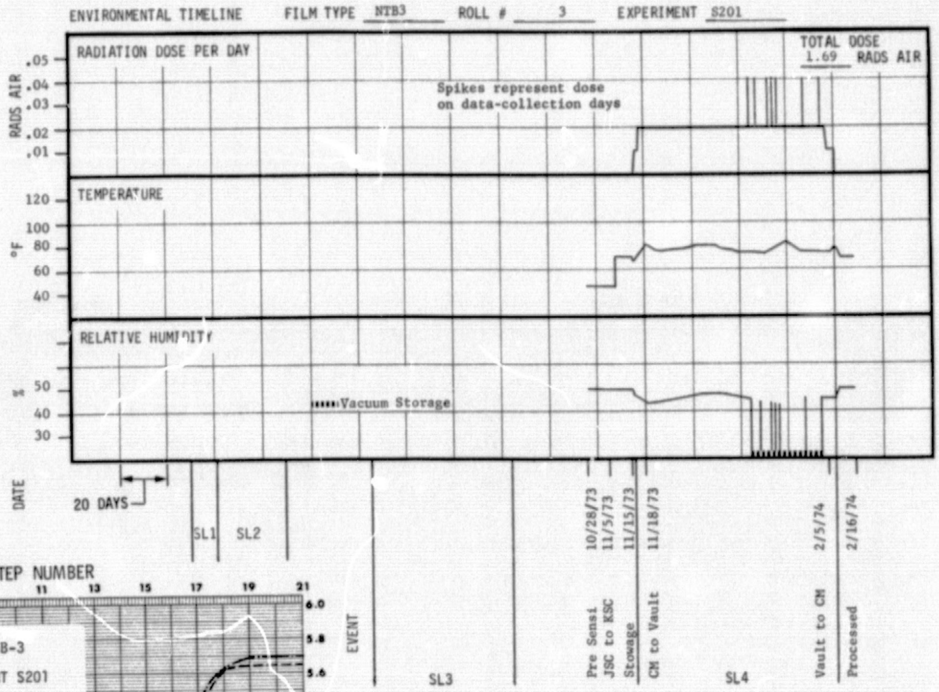


FIGURE D-2 H&D CURVE FAMILIES; FILM TYPE NTB3, ROLLS 1 & 2



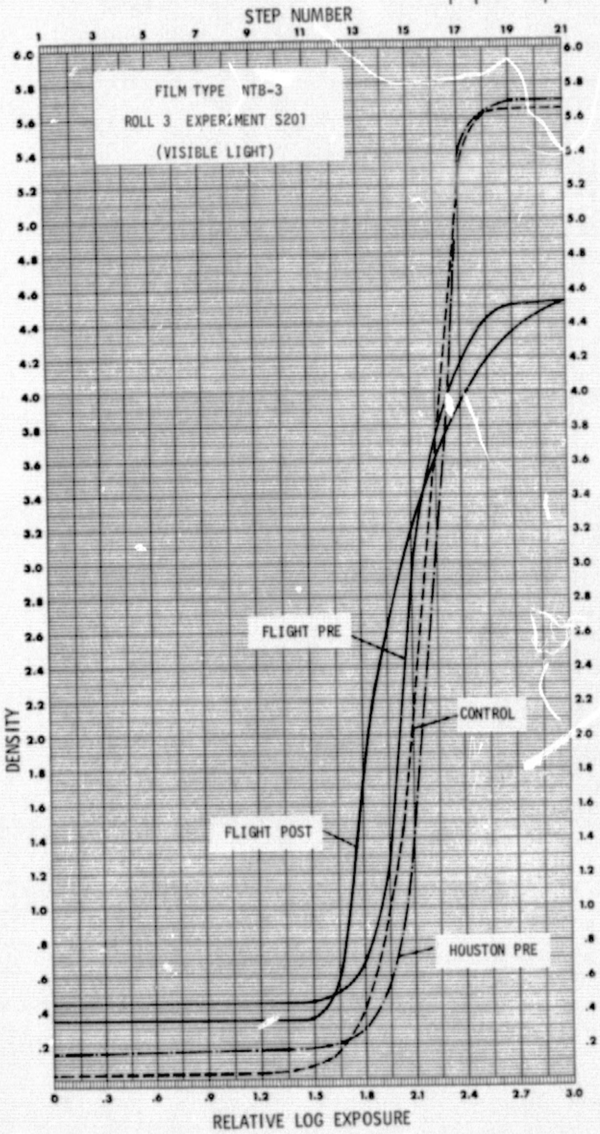
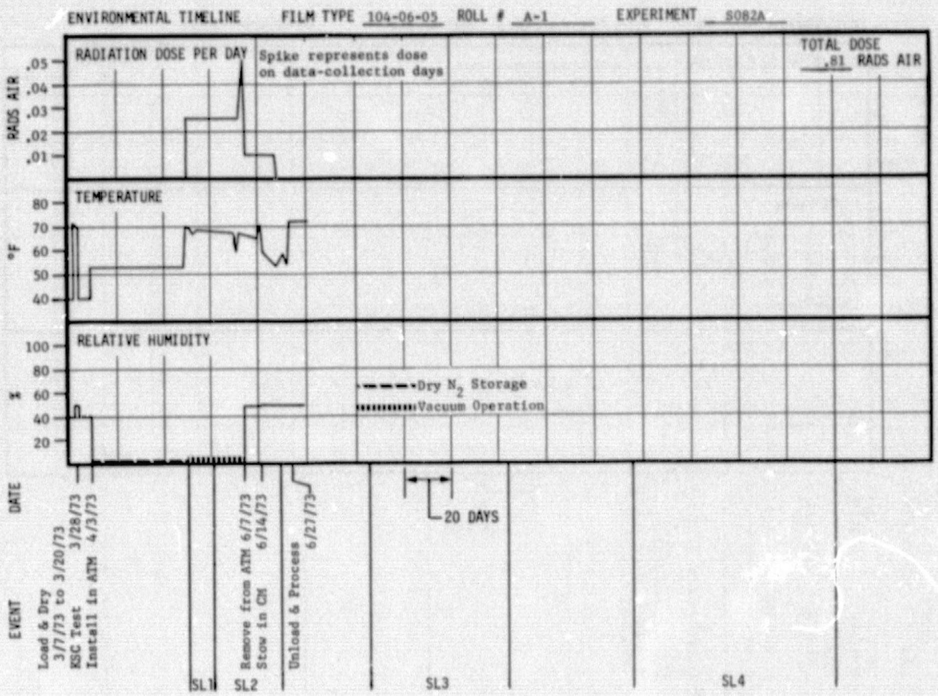


FIGURE D-3 ENVIRONMENTAL TIMELINE; H&D CURVE FAMILY; FILM TYPE NTB3, ROLL 3



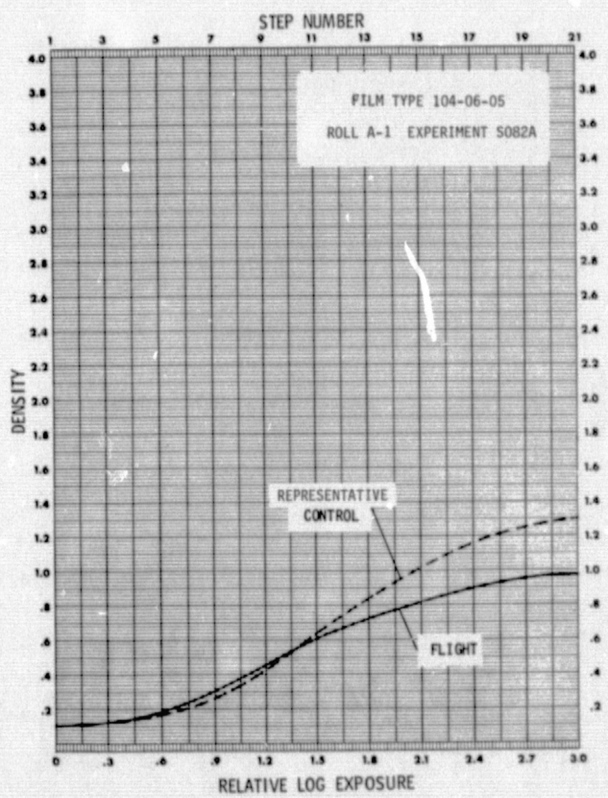
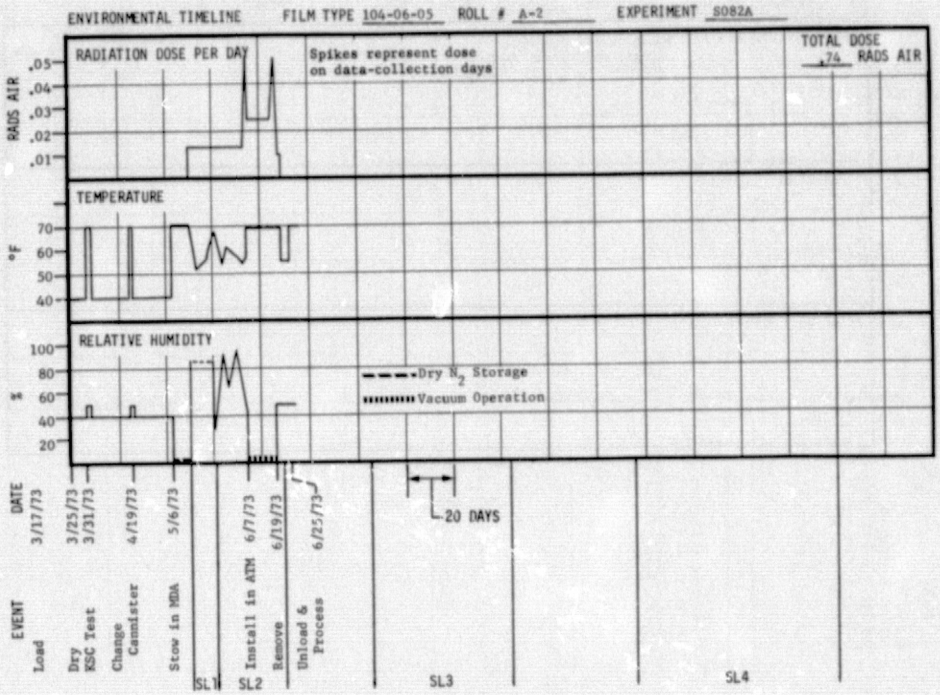


FIGURE D-4 FILM TYPE 104-06-05, CARROUSEL A-1



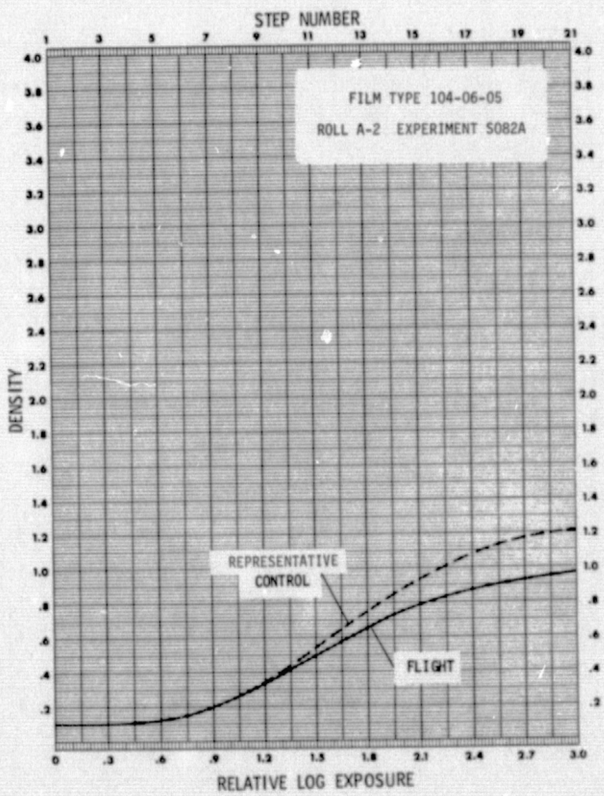
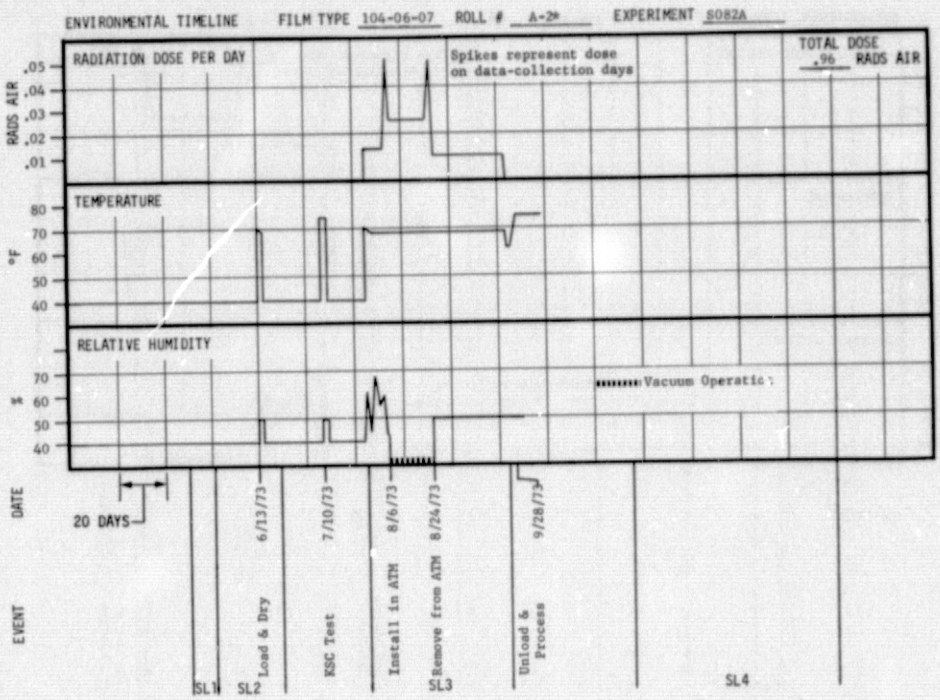


FIGURE D-5, FILM TYPE 104-06-05, CARROUSEL A-2



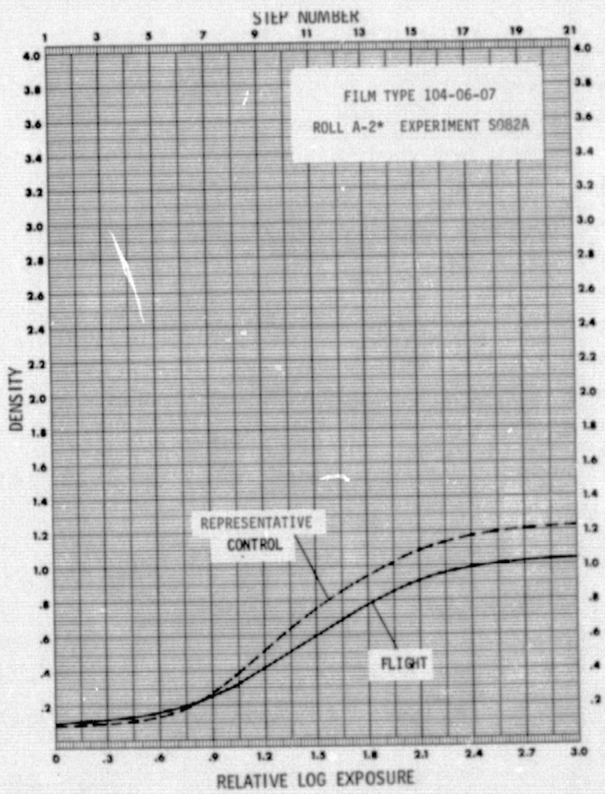
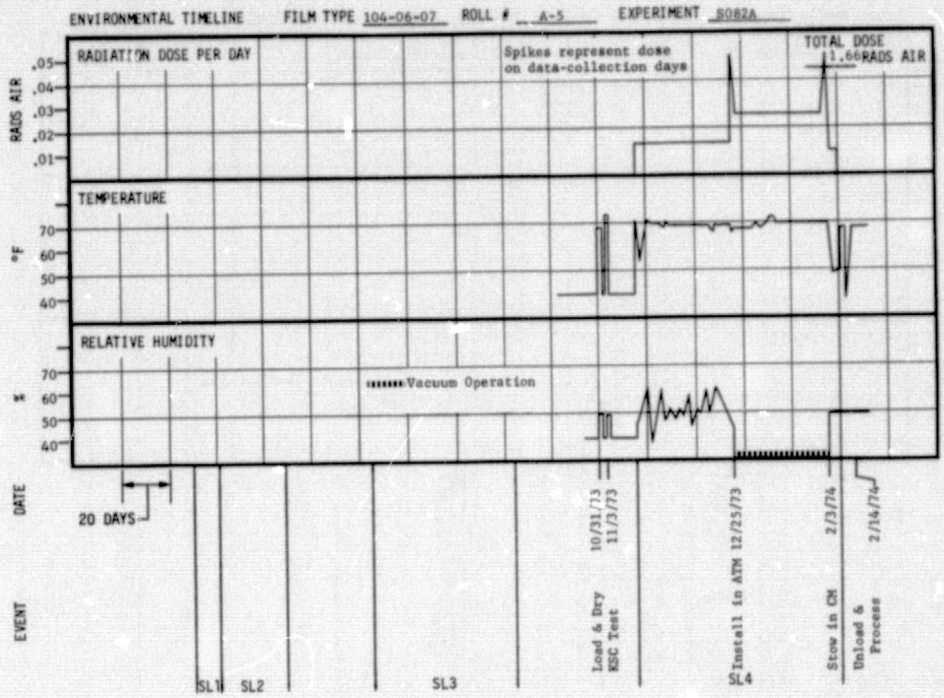


FIGURE D-6, FILM TYPE 104-06-07, CARROUSEL A-2*



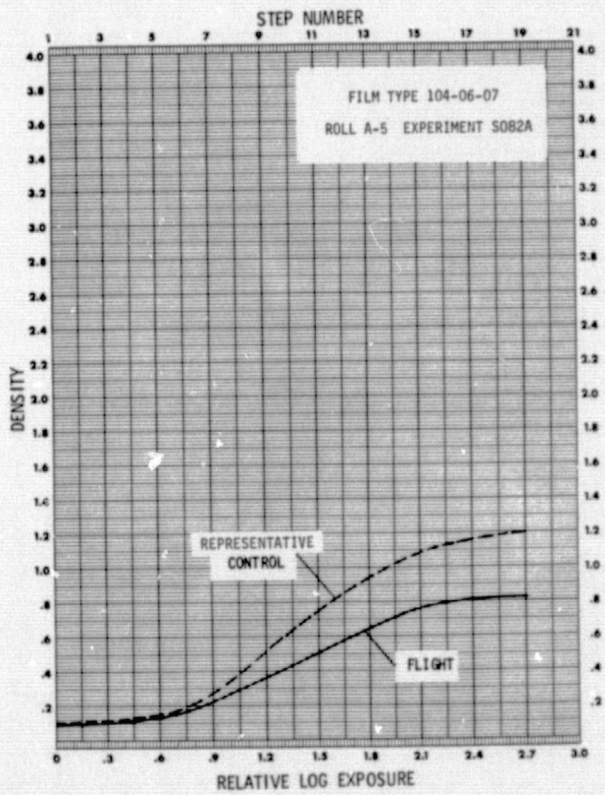
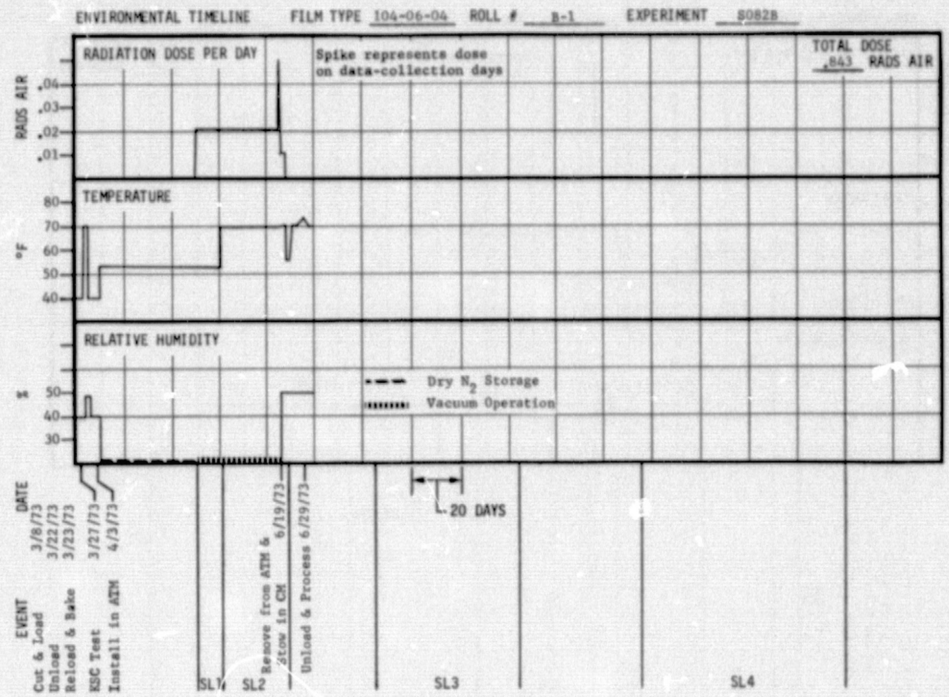


FIGURE D-7, FILM TYPE 104-06-07, CARROUSEL A-5



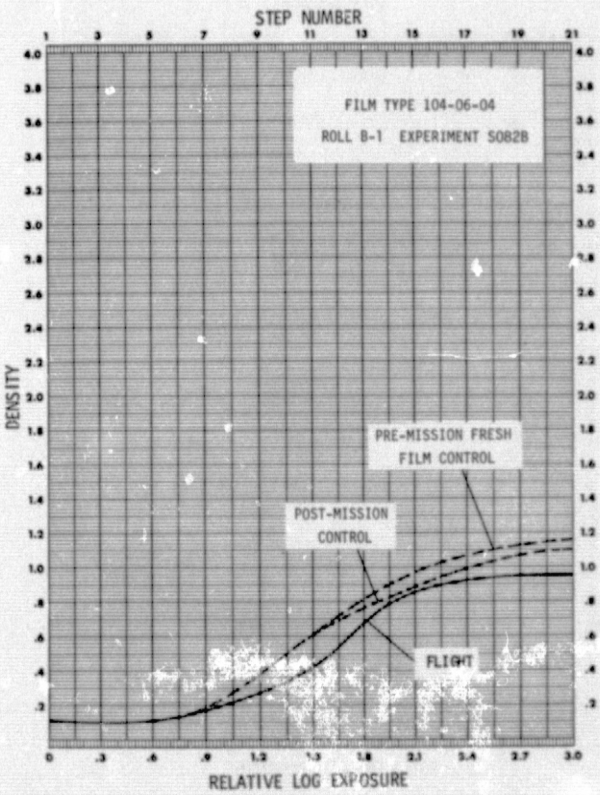
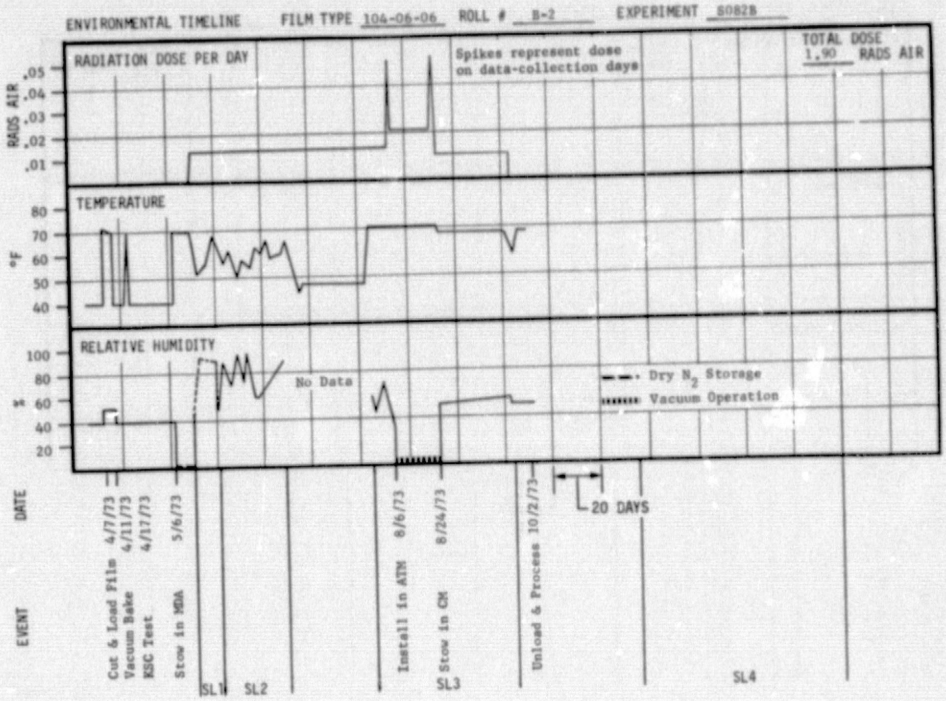


FIGURE D-8, FILM TYPE 104-06-04, CARROUSEL B-1



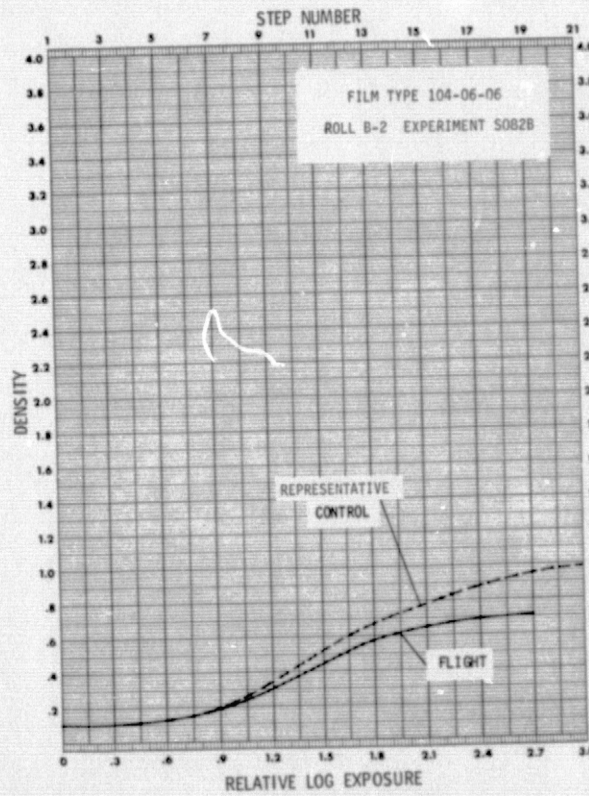
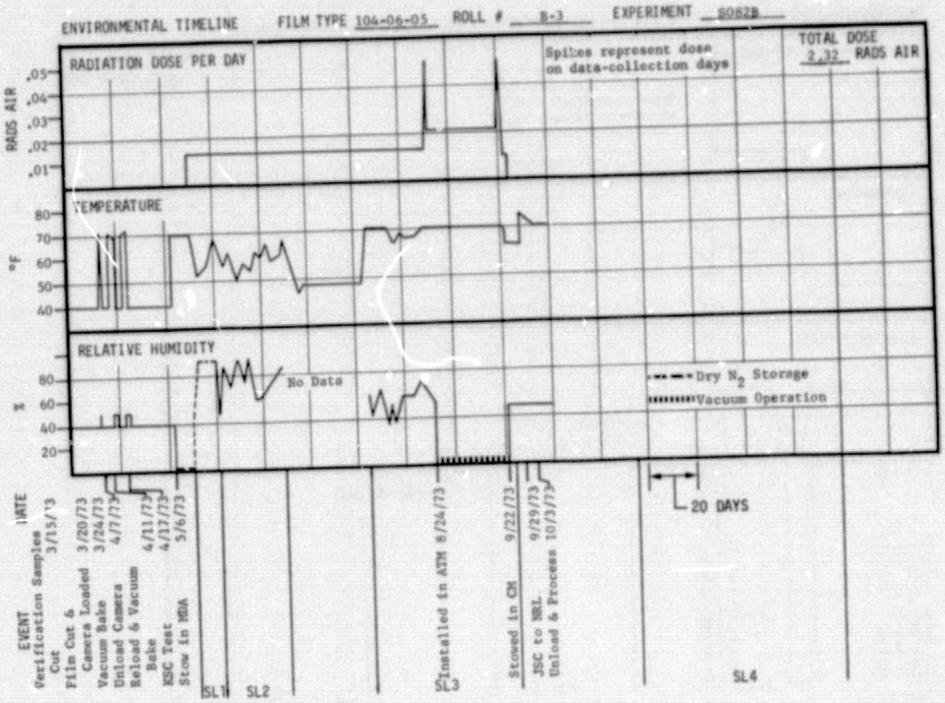


FIGURE D-9, FILM TYPE 104-06-06, CARROUSEL B-2



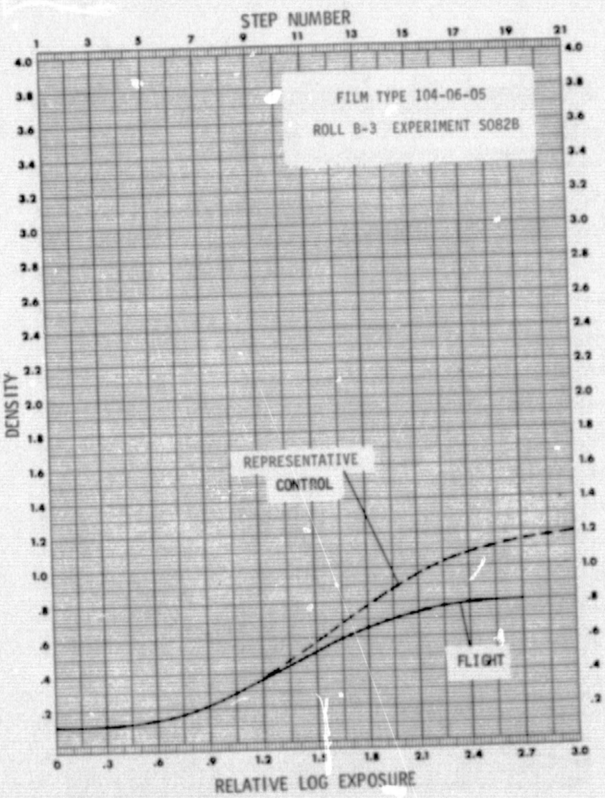
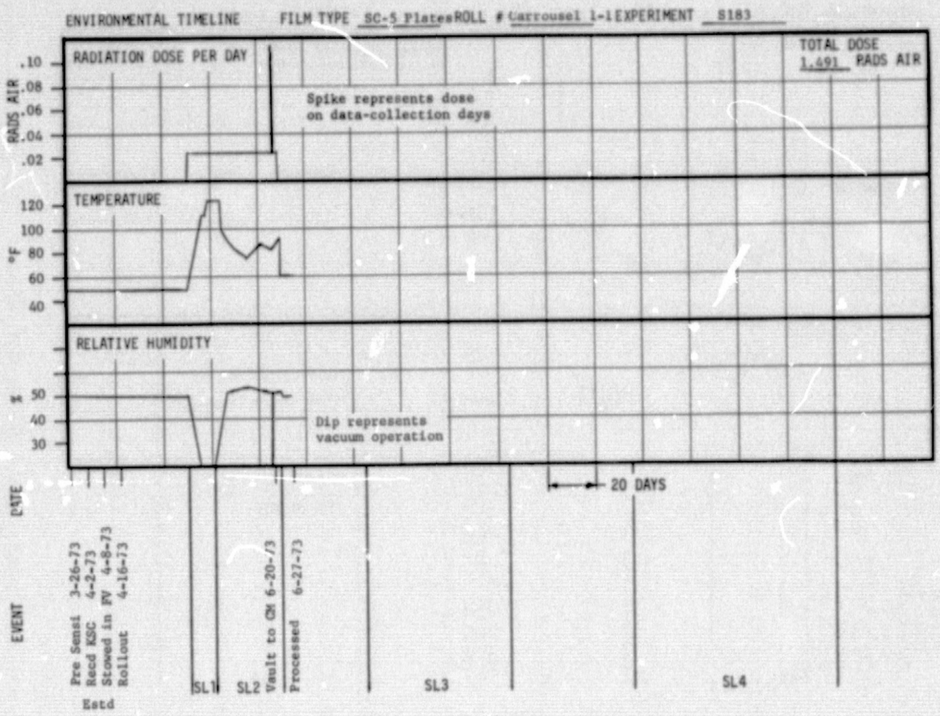


FIGURE D-10, FILM TYPE 104-06-05, CARROUSEL B-3



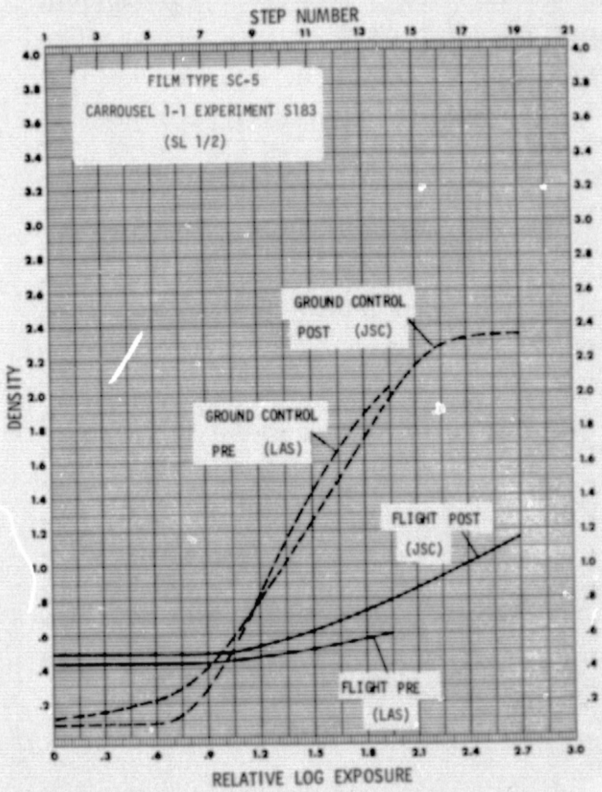
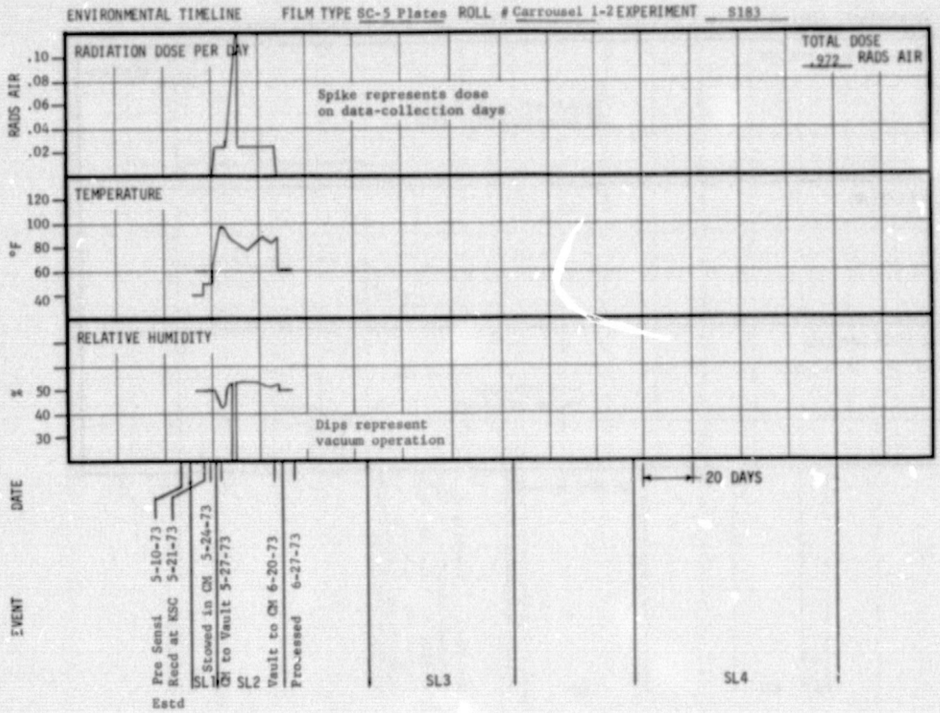


FIGURE D-11, FILM TYPE SC-5, CARROUSEL 1-1 (SL1/2)



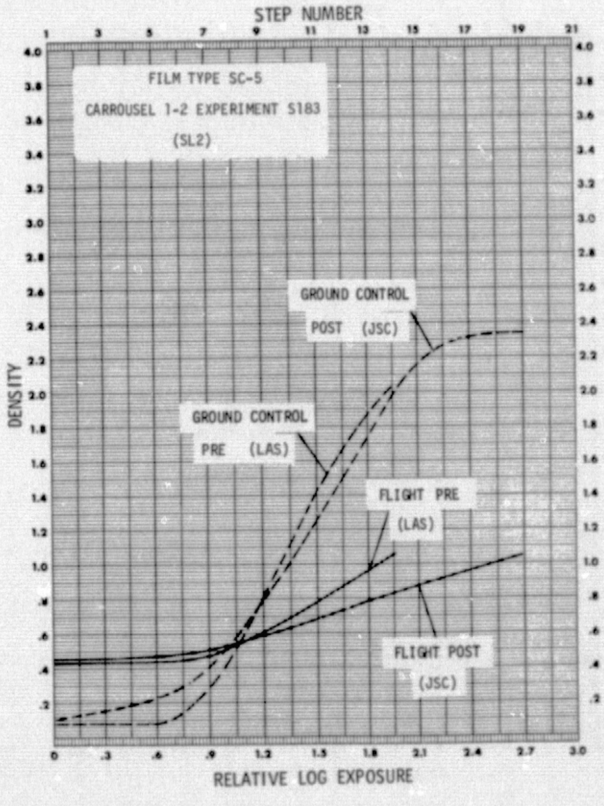
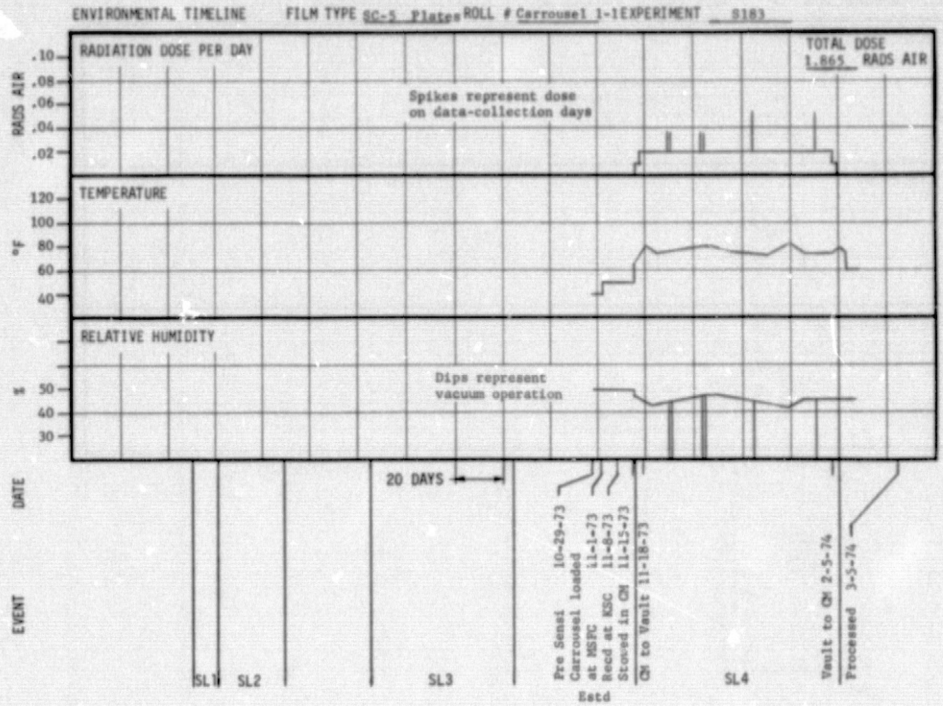


FIGURE D-12. FILM TYPE SC-5, CARROUSEL 1-2 (SL2)



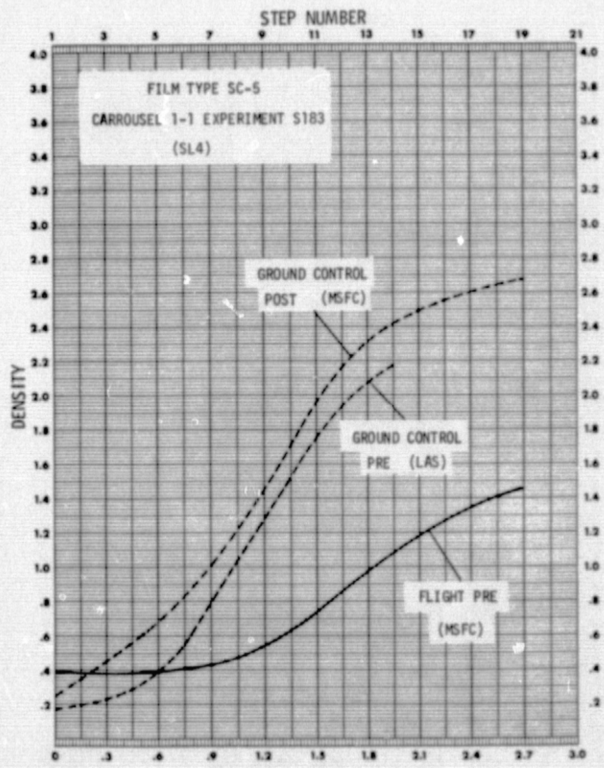
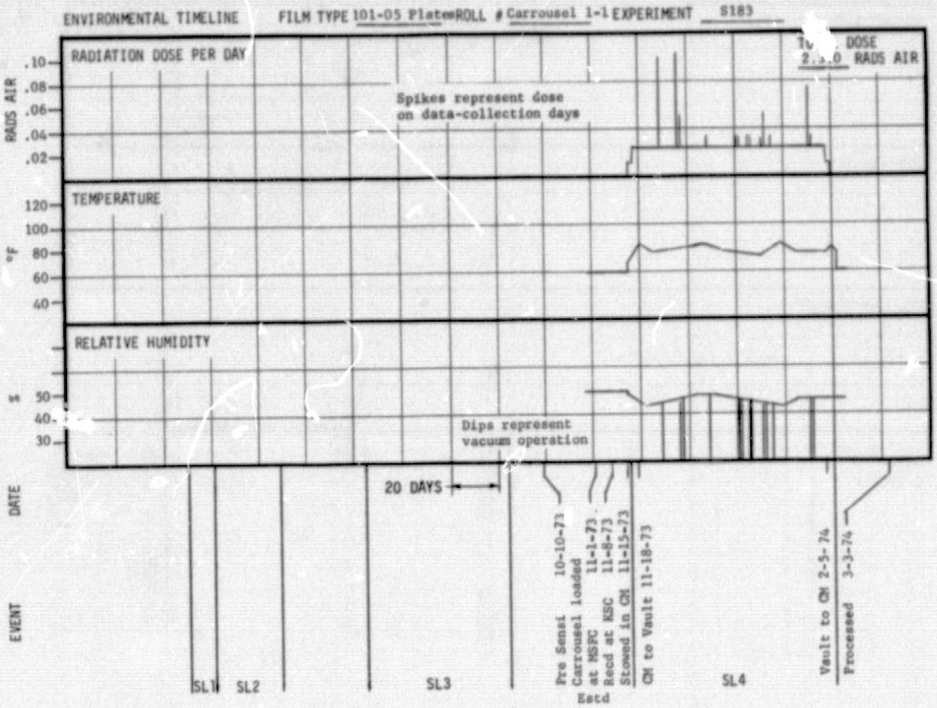
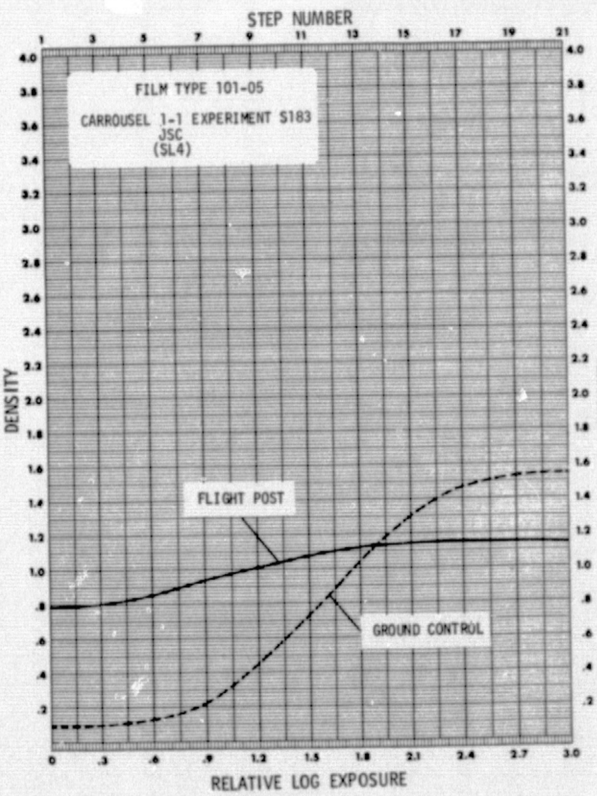


FIGURE D-13, FILM TYPE SC-5, CARROUSEL 1-1 (SL4)





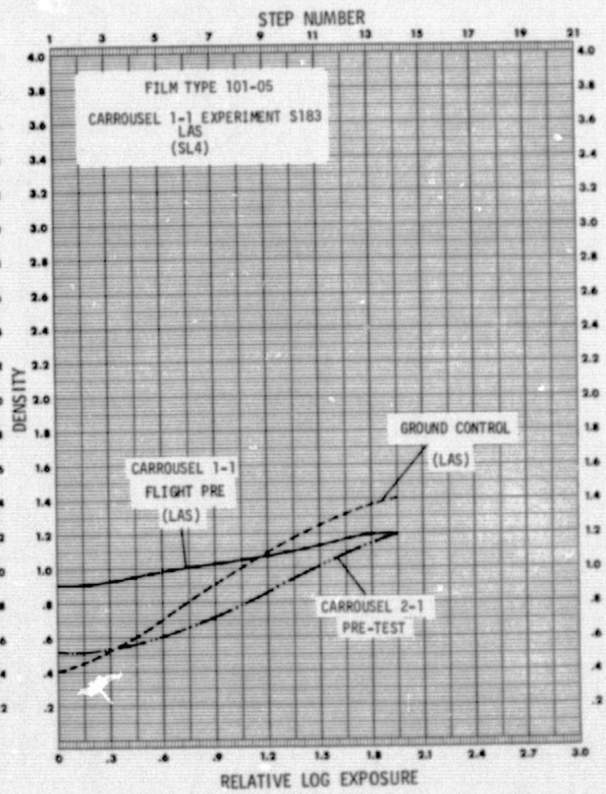
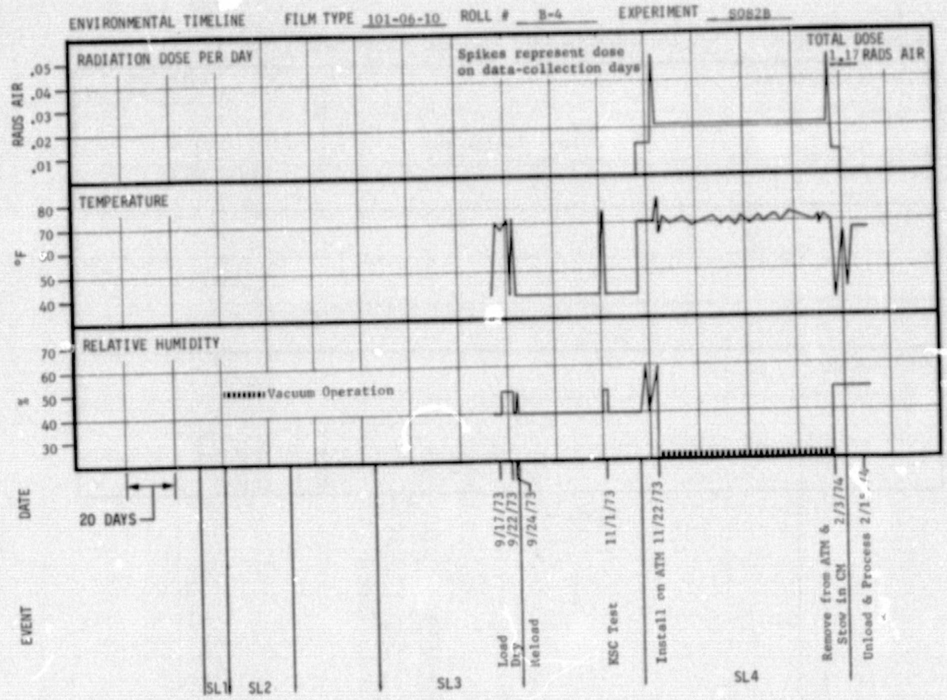


FIGURE D-14, FILM TYPE 101-05, CARROUSEL 1-1 (SL4)



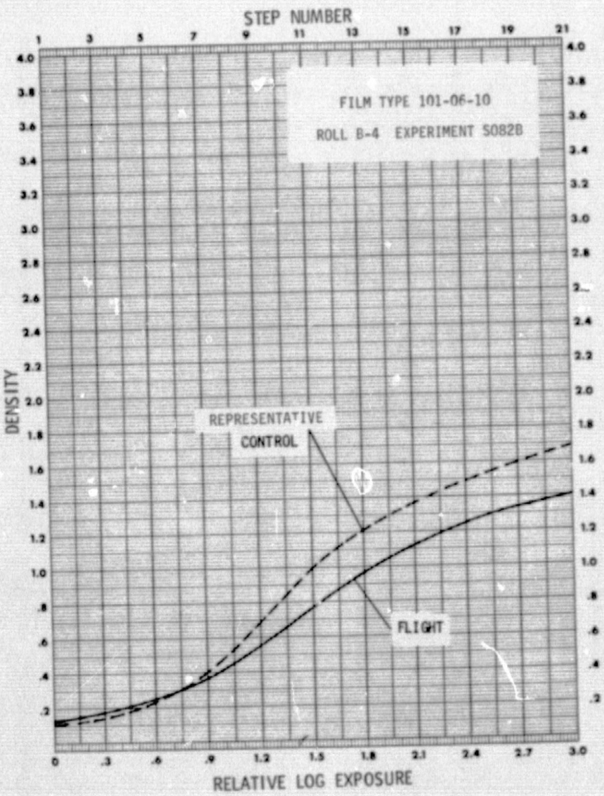
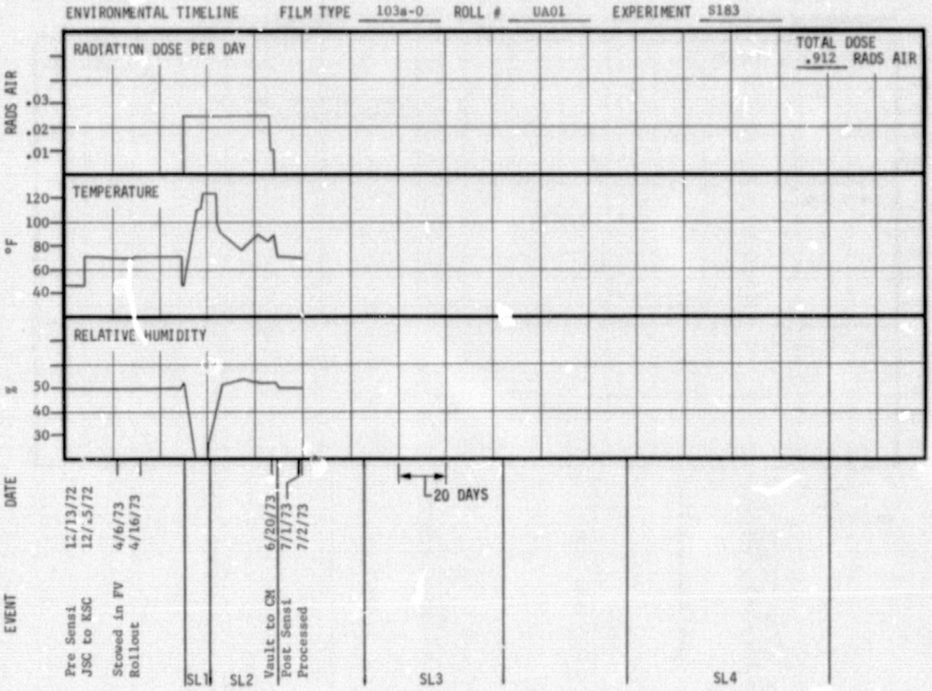


FIGURE D-15, FILM TYPE 101-06, CARROUSEL B-4



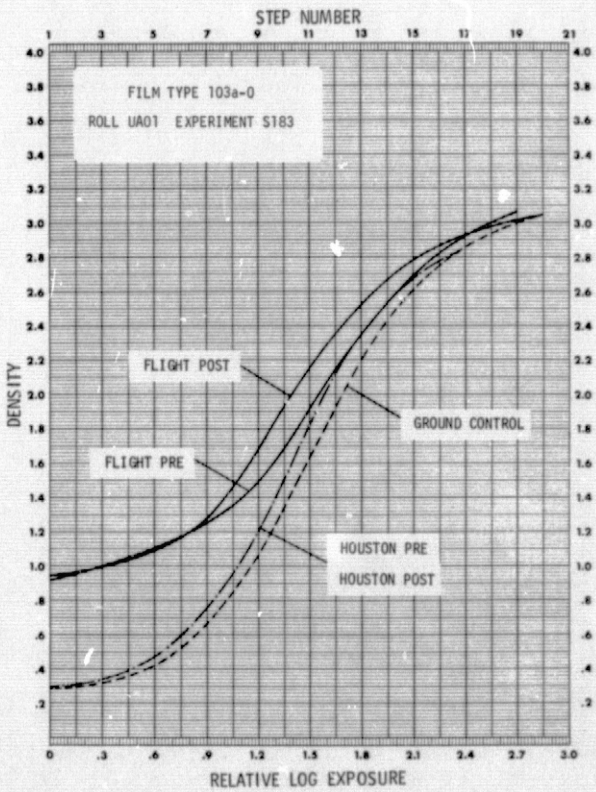
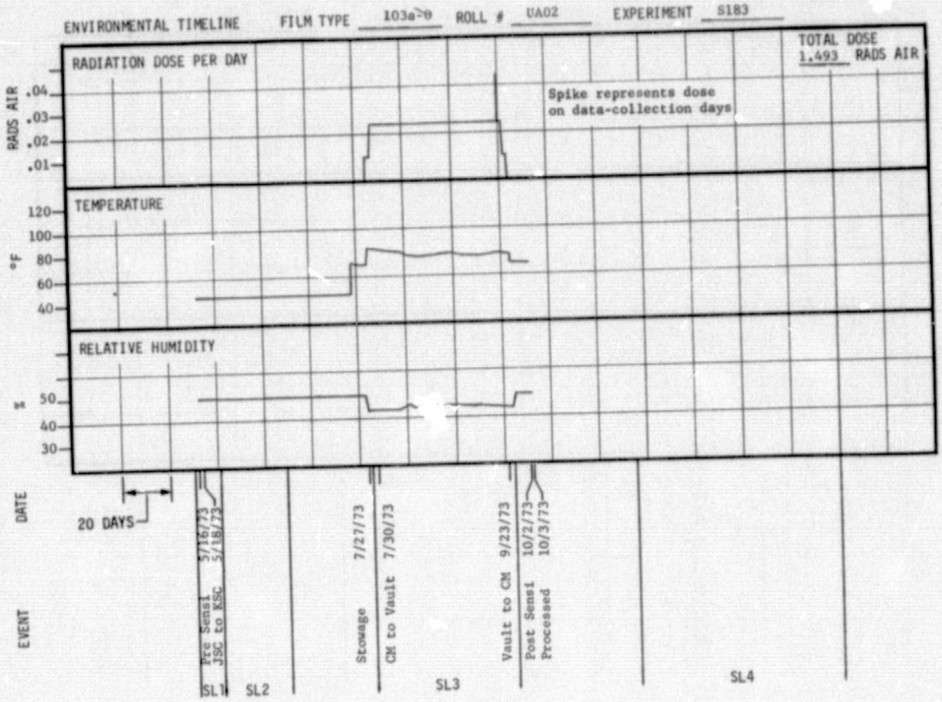


FIGURE D-16, FILM TYPE 103a-o, ROLL UA01



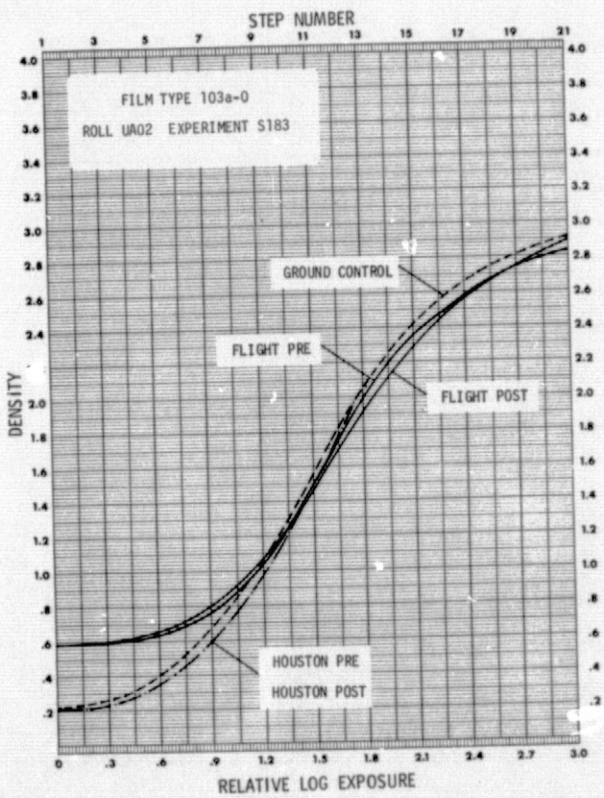
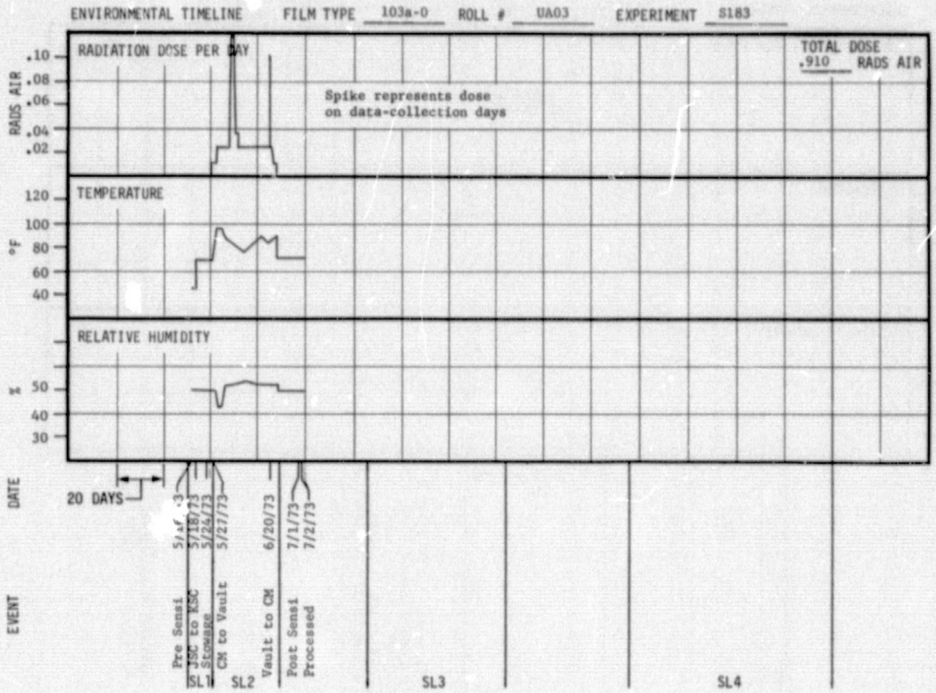


FIGURE D-17, FILM TYPE 103a-o, ROLL UA02



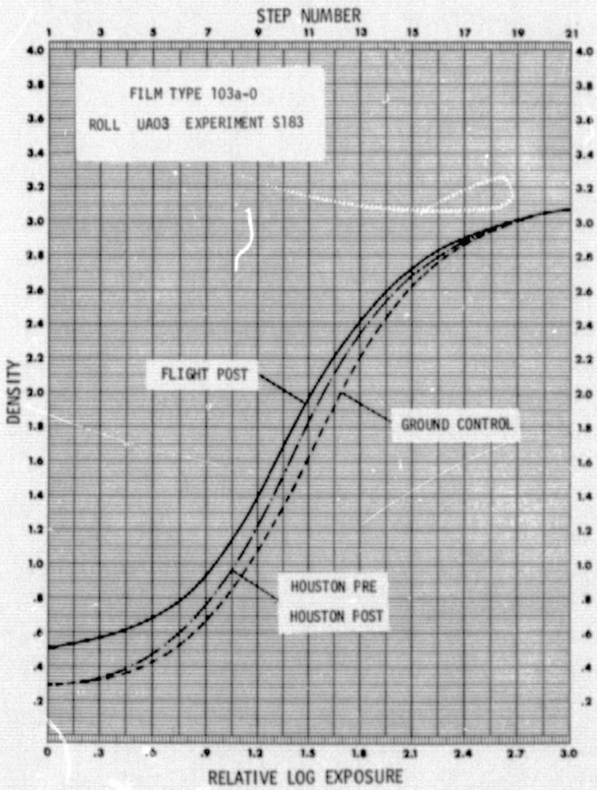
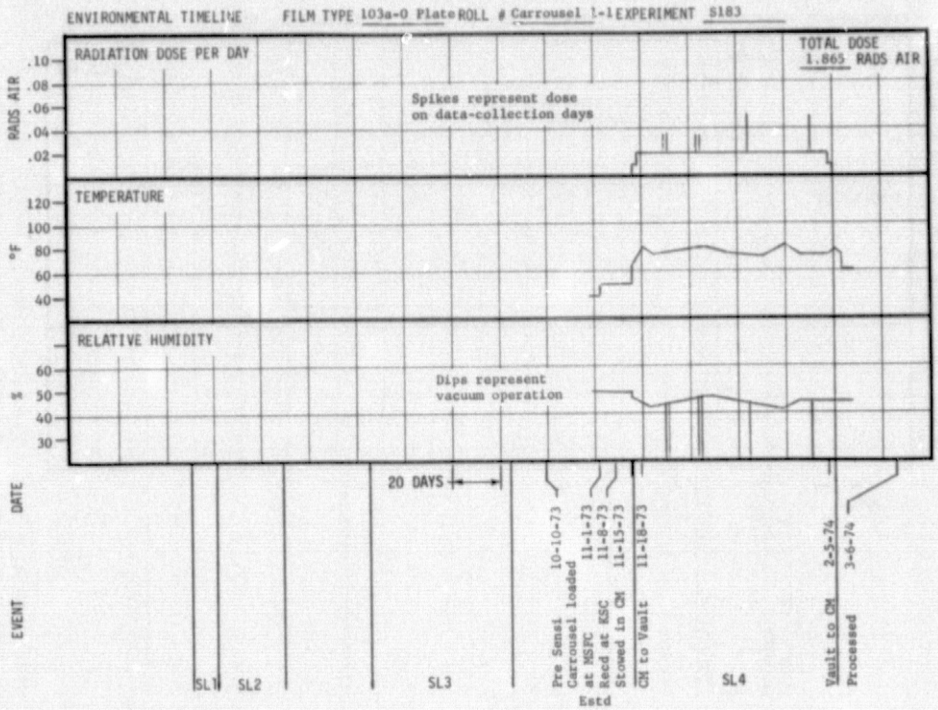


FIGURE D-18, FILM TYPE 103a-o, ROLL UA02



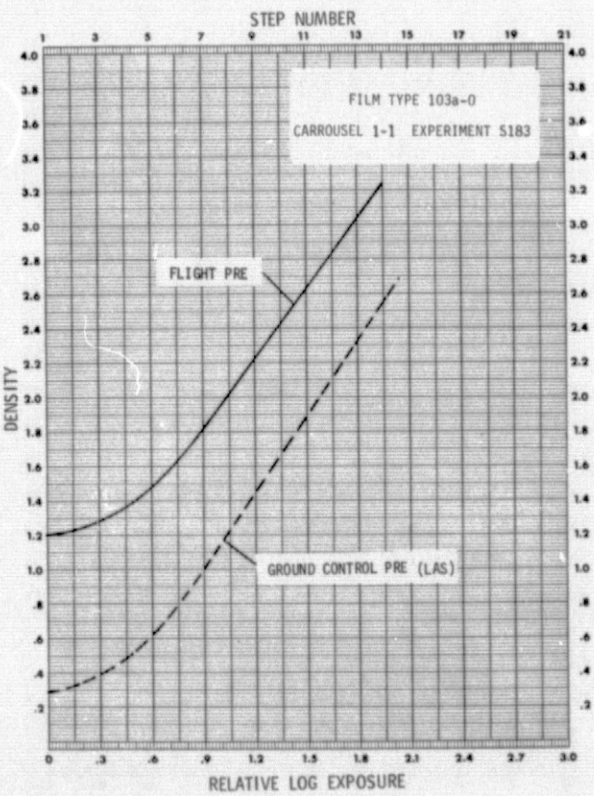
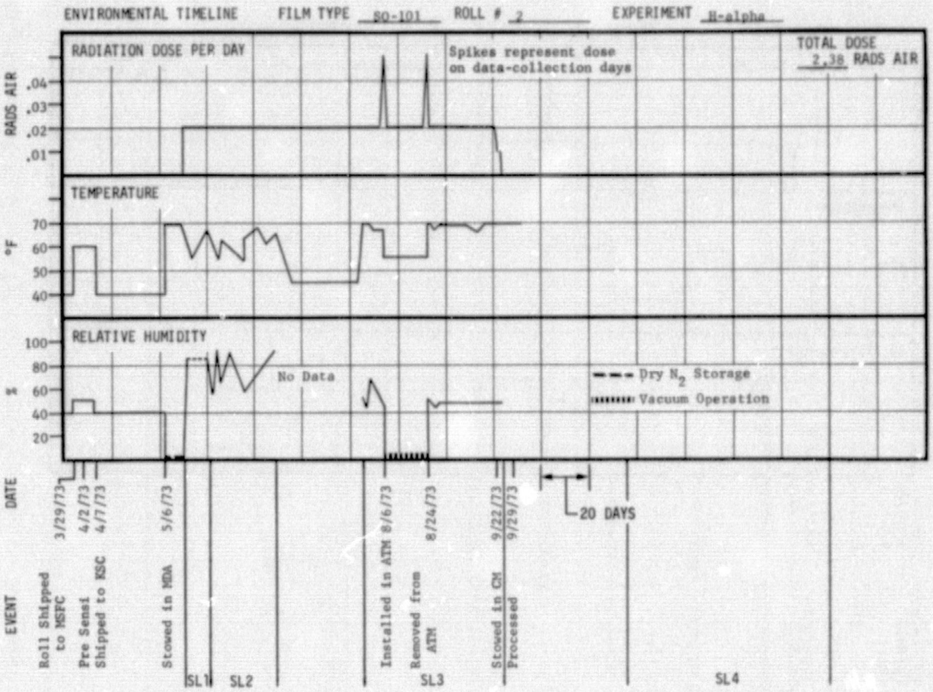


FIGURE D-19, FILM TYPE 103a-o, CARROUSEL 1-1



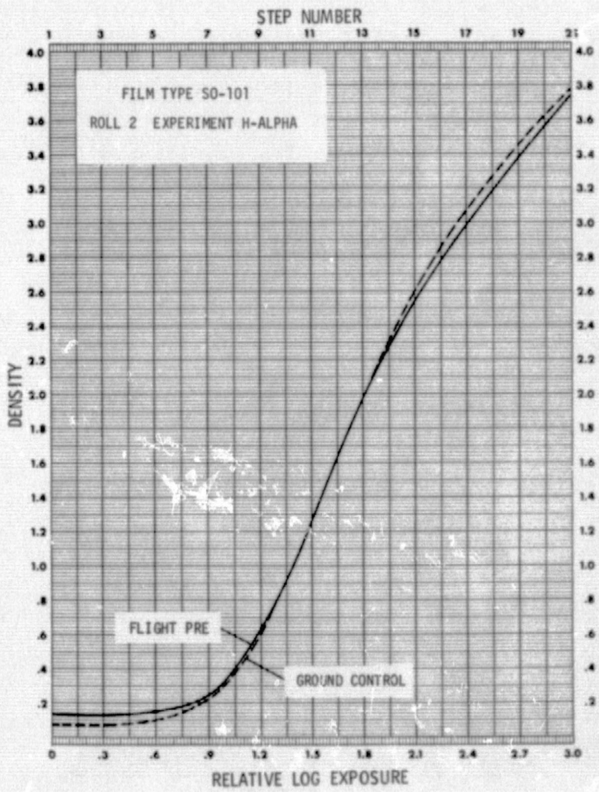
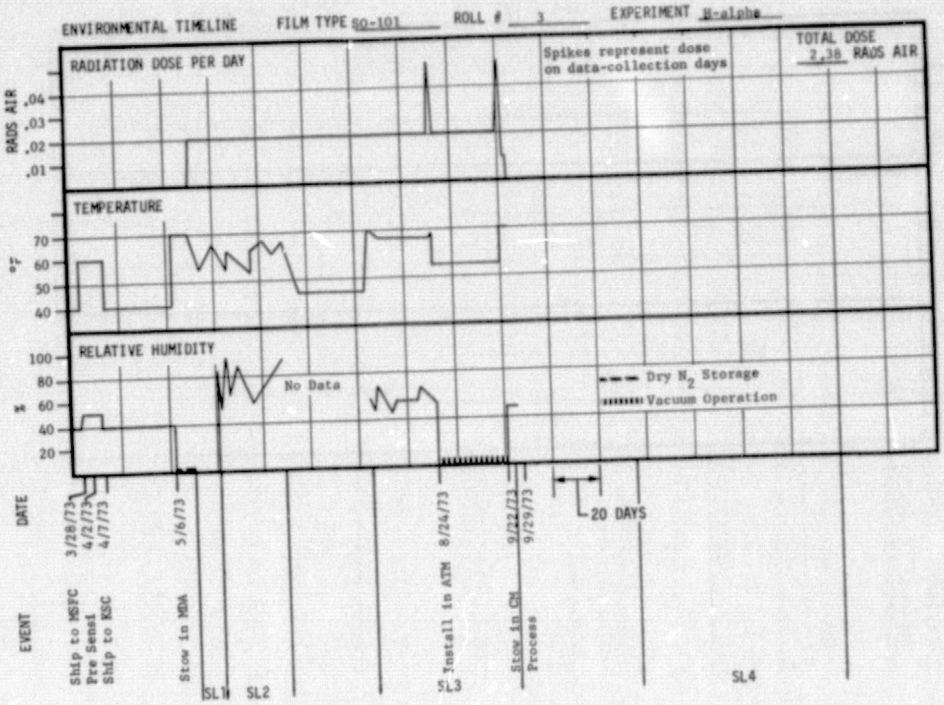


FIGURE D-20, FILM TYPE SO-101, ROLL 2



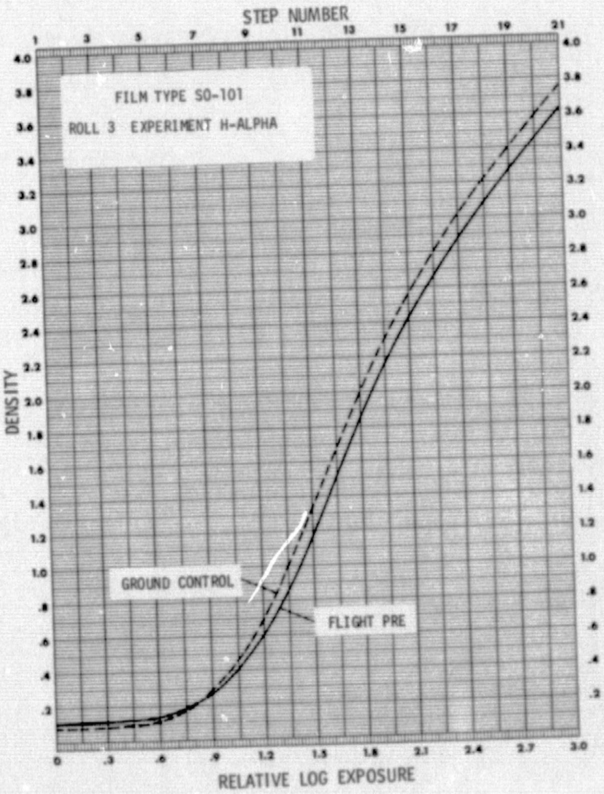
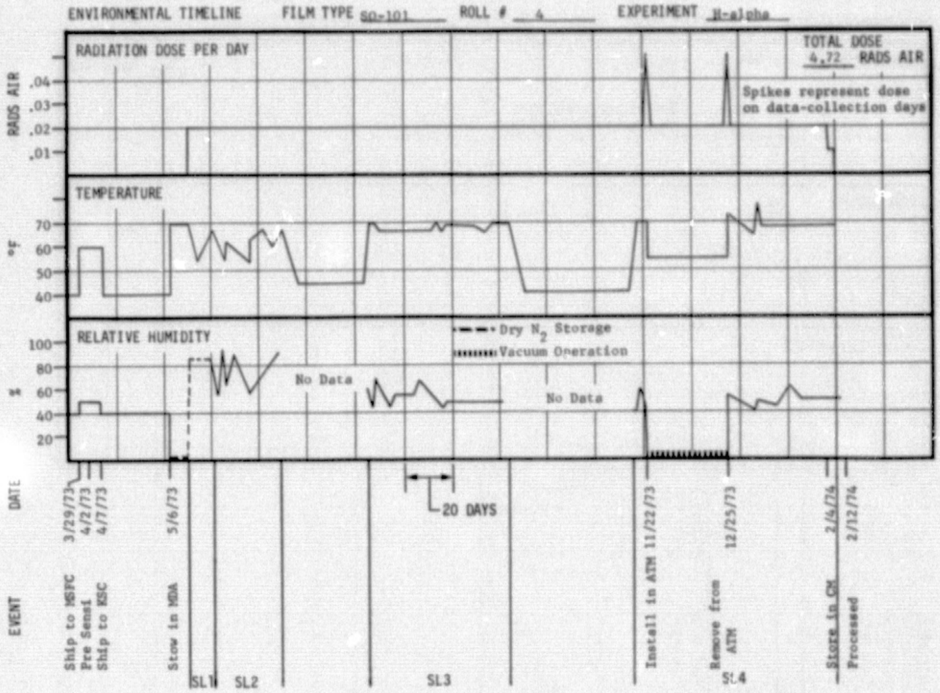


FIGURE D-21, FILM TYPE SO-101, ROLL 3



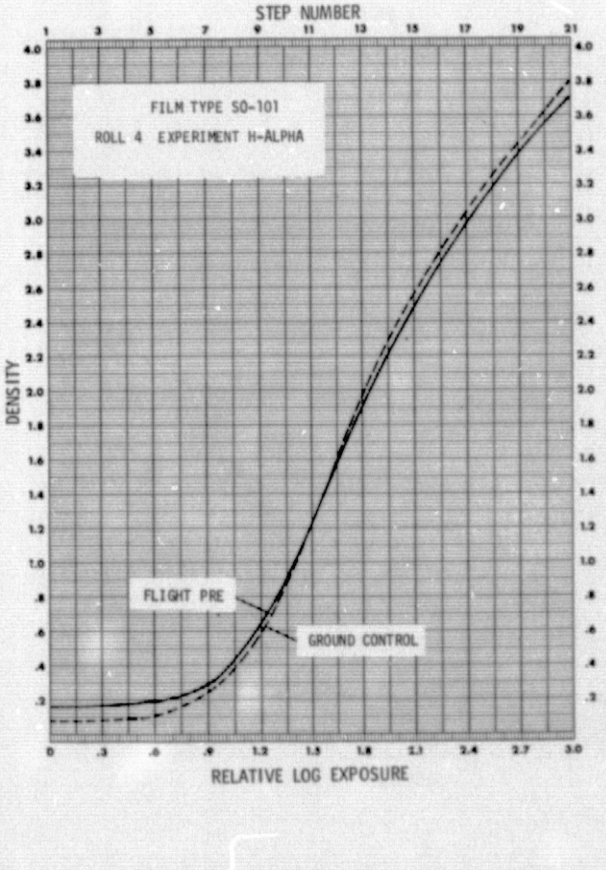
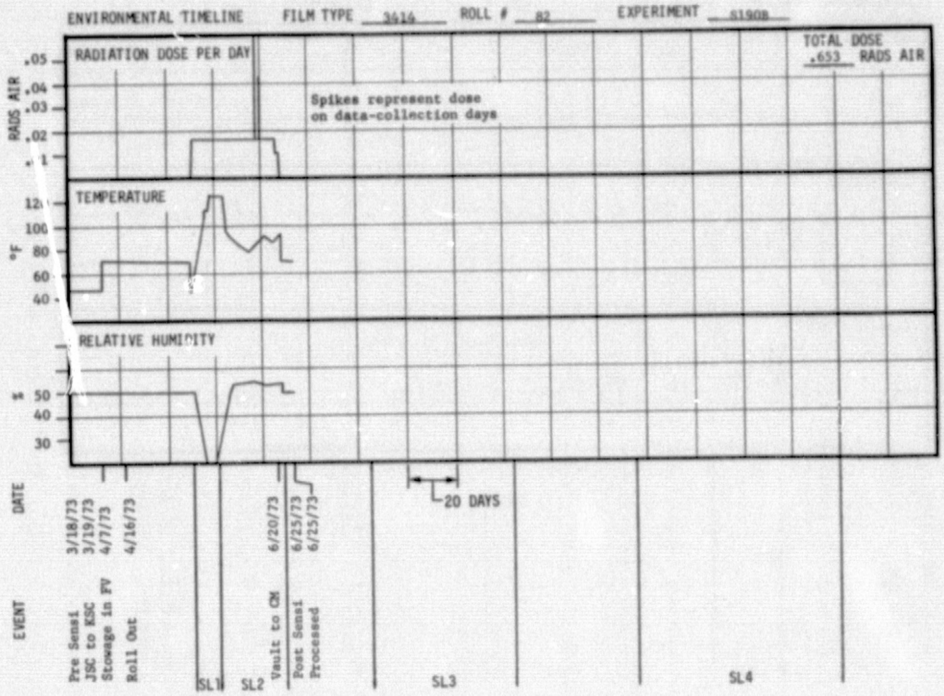


FIGURE D-22, FILM TYPE SO-101, ROLL 4



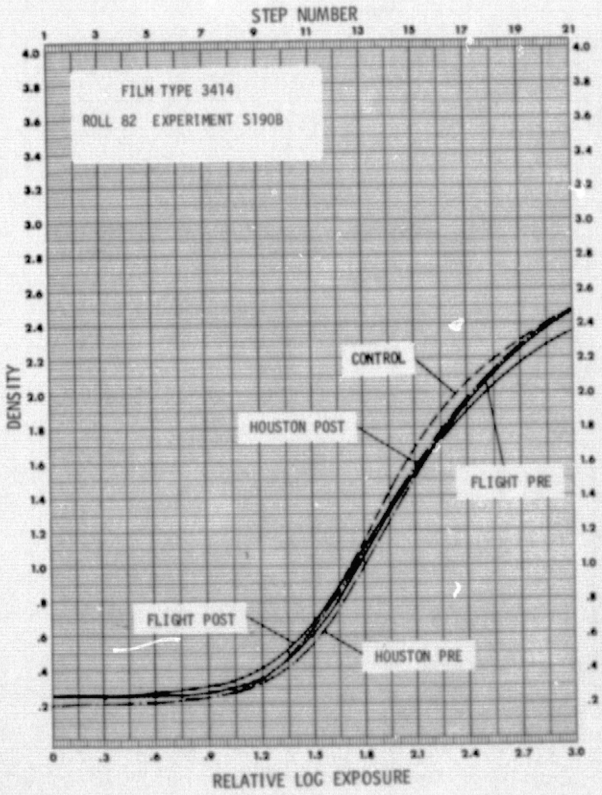
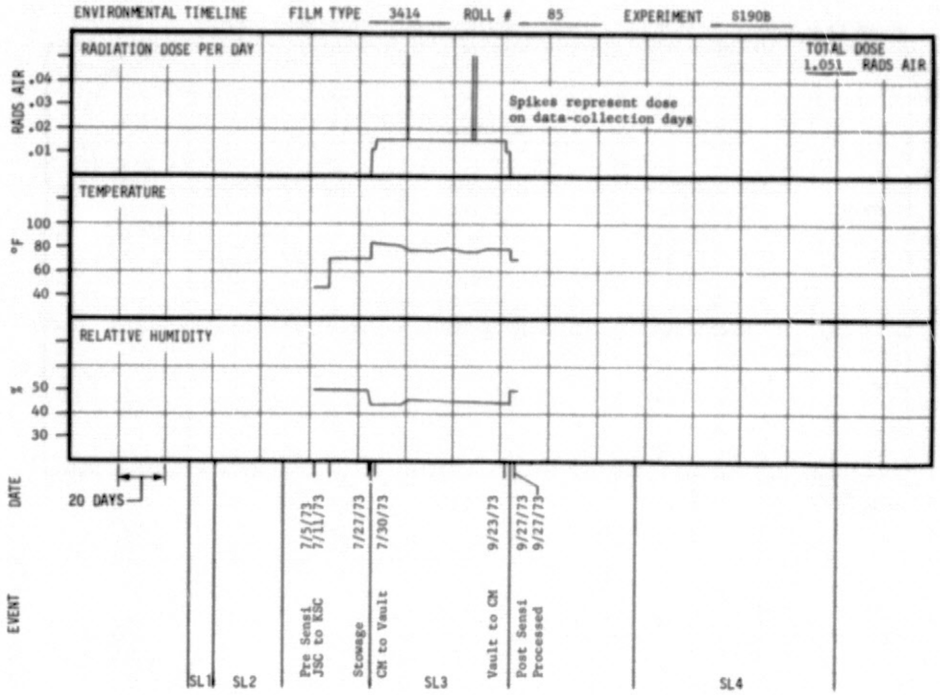


FIGURE D-23, FILM TYPE 3414, ROLL 82



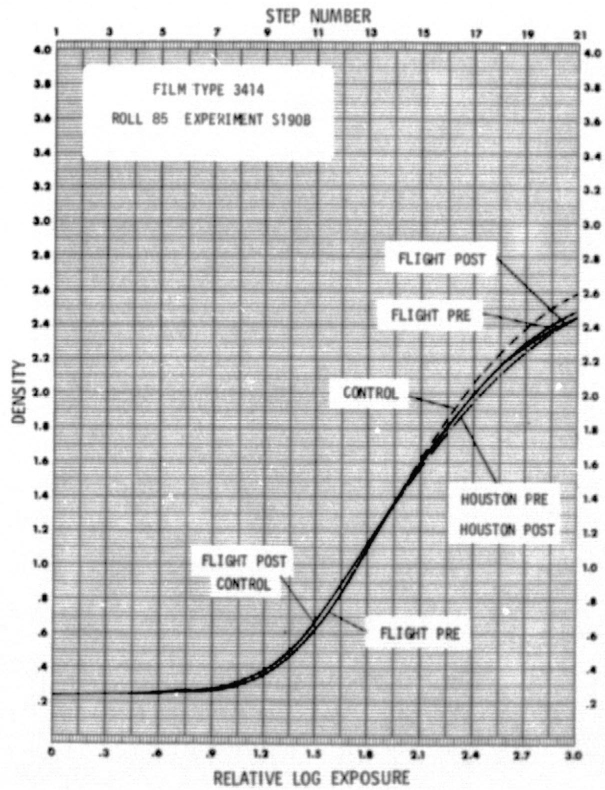
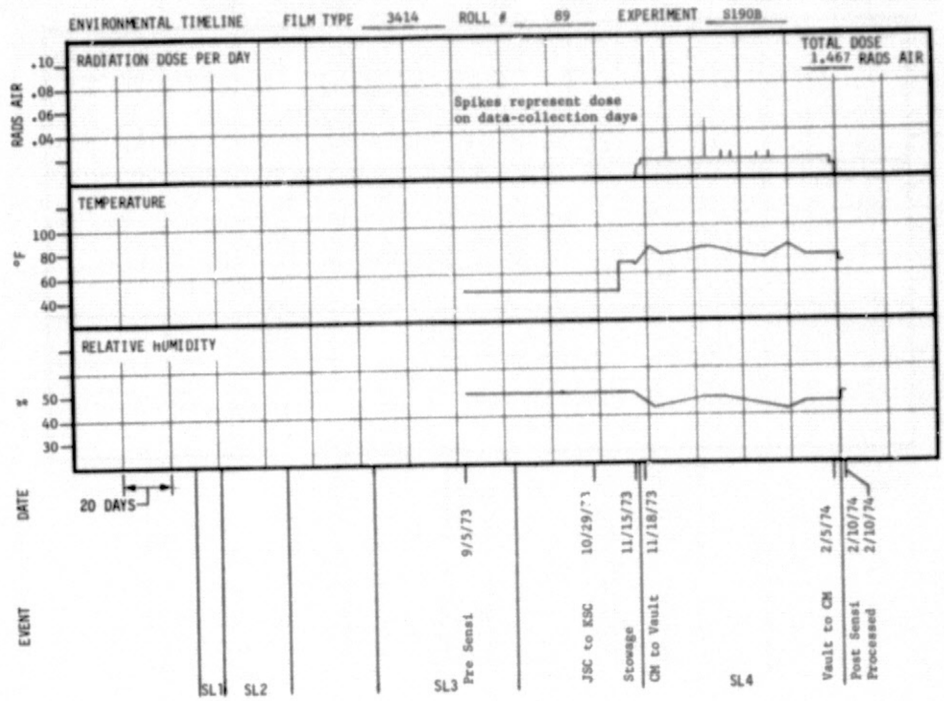


FIGURE D-24, FILM TYPE 3414, ROLL 85



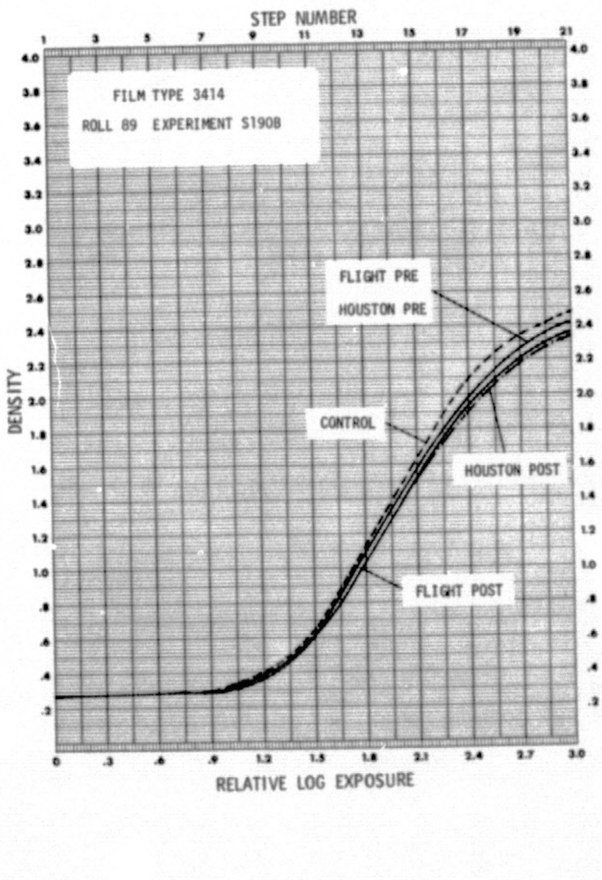
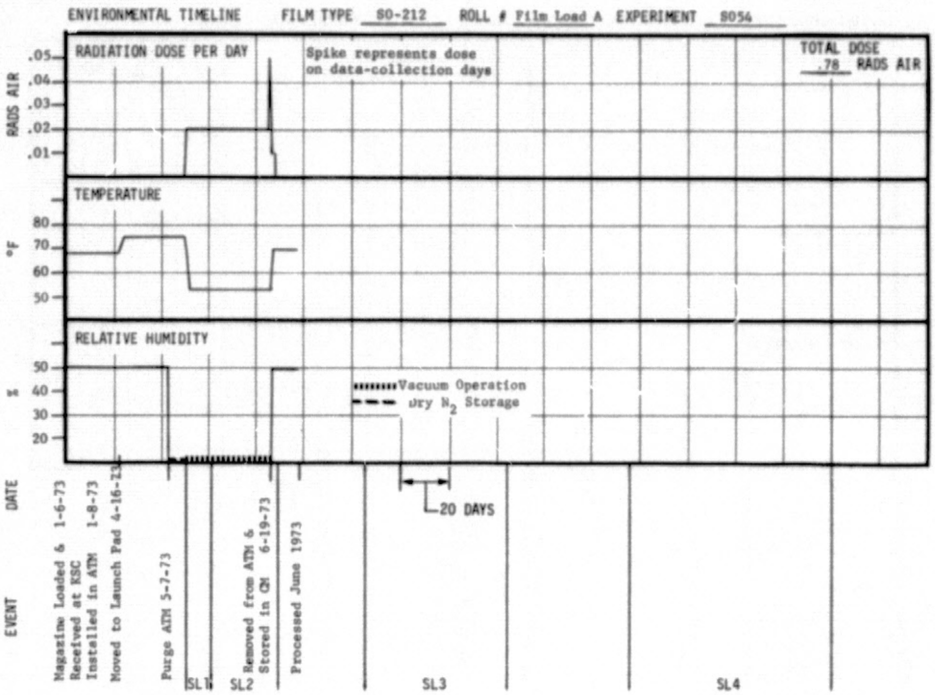


FIGURE D-25, FILM TYPE 3414, ROLL 89



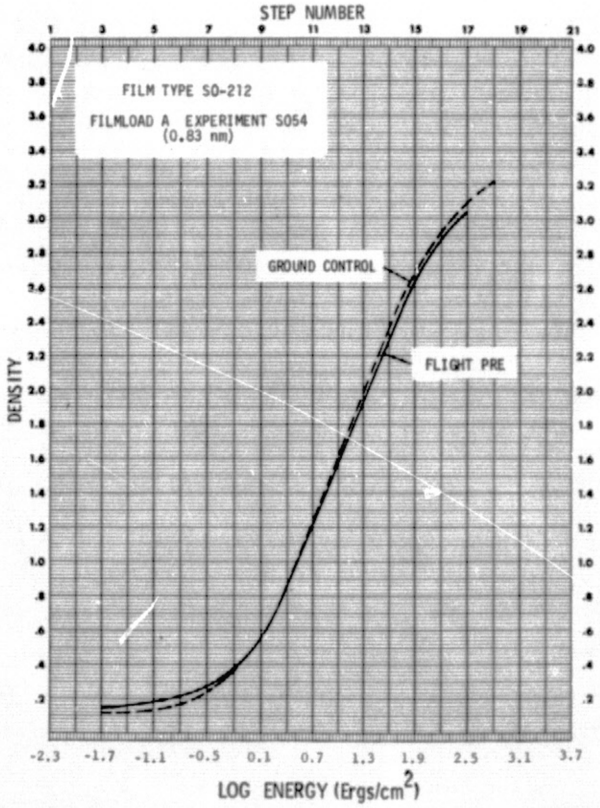
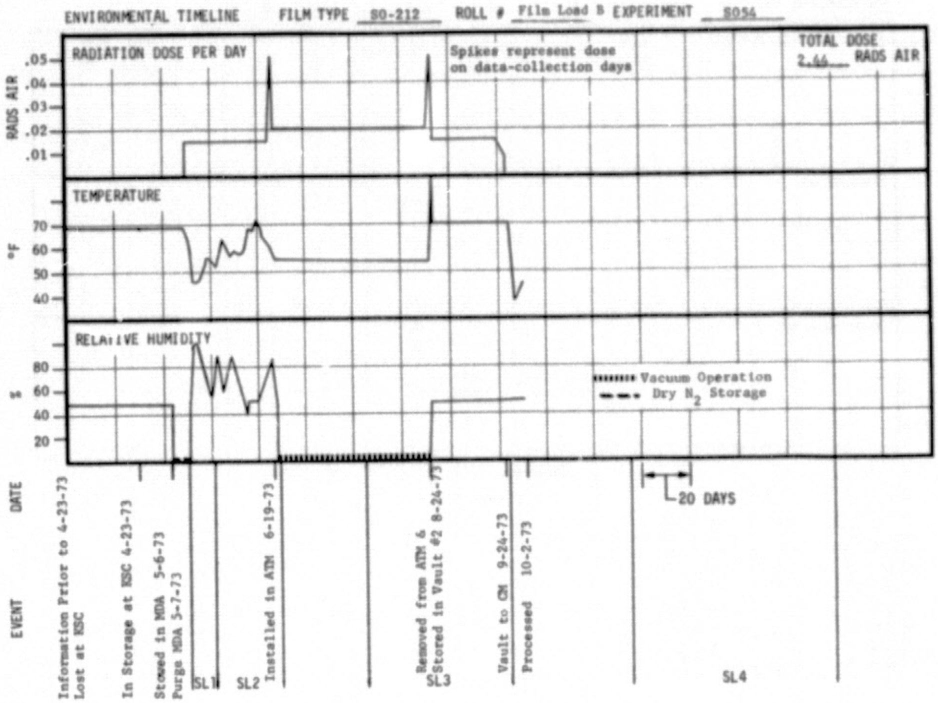
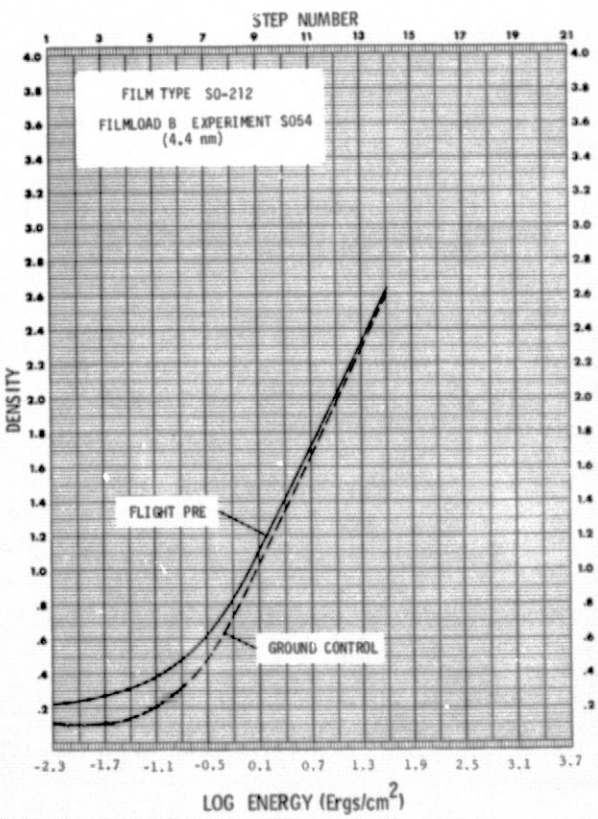


FIGURE D-26, FILM TYPE SO-212, FILM LOAD A (S054)





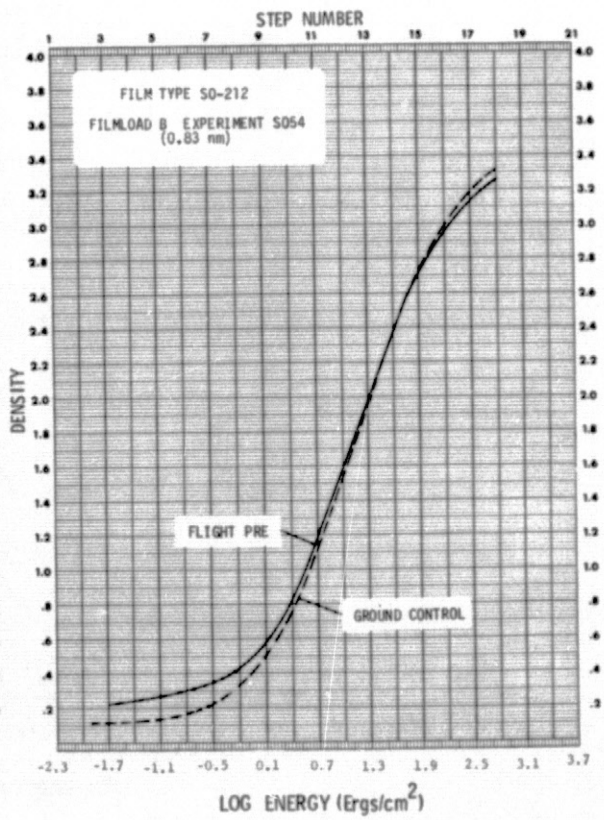
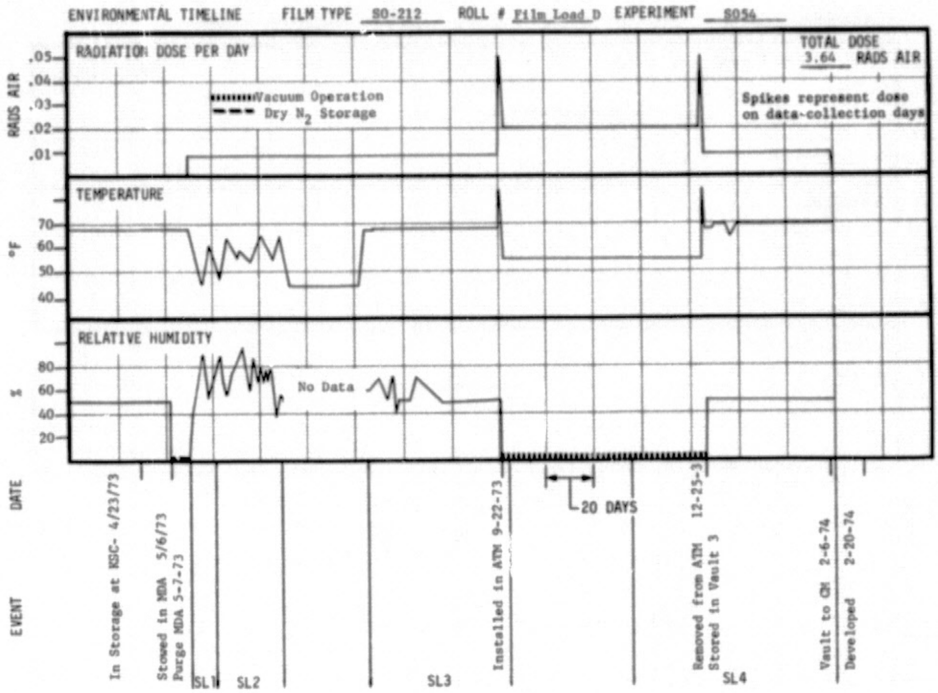


FIGURE D-27, FILM TYPE SO-212, FILM LOAD B (S054)



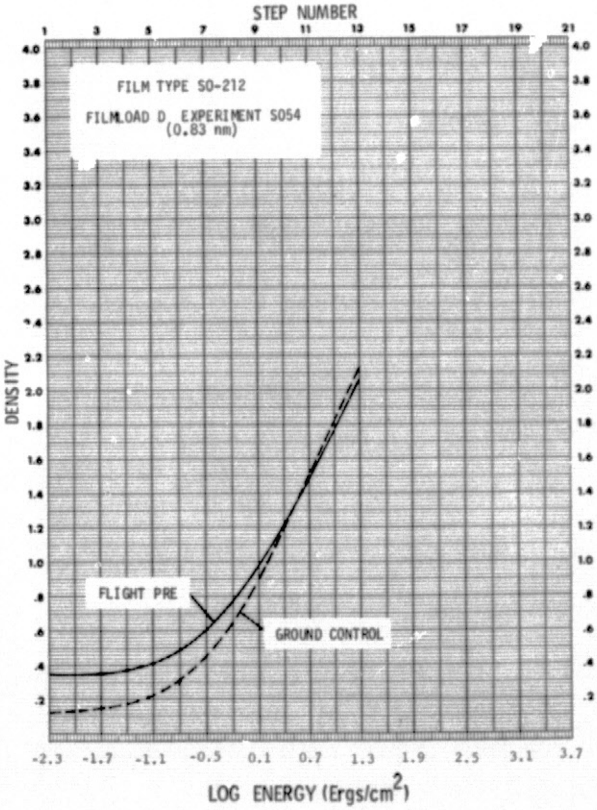
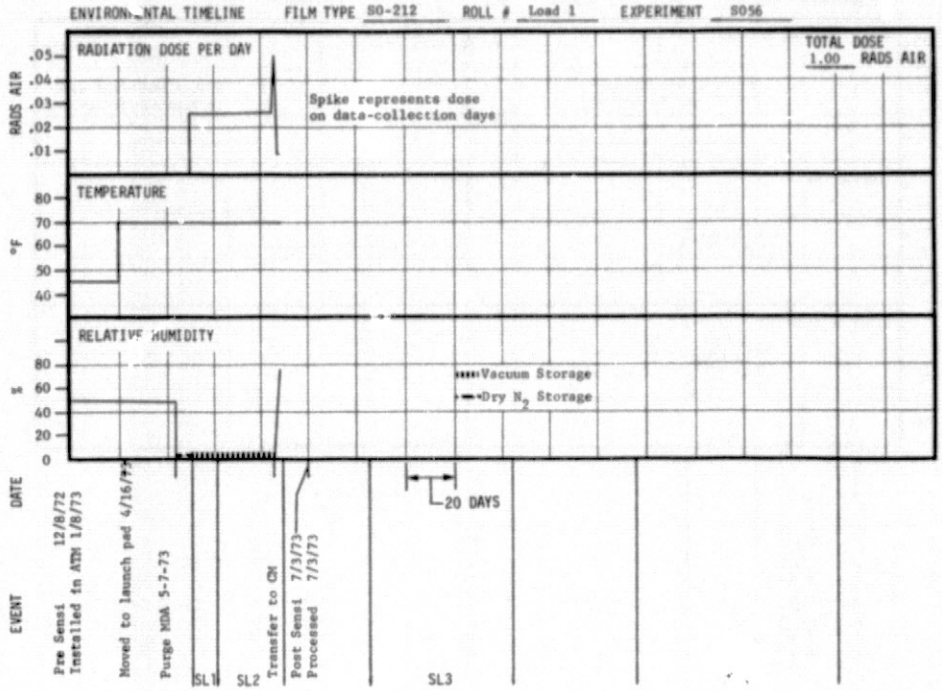


FIGURE D-28, FILM TYPE SO-212, FILM LOAD D (S054)



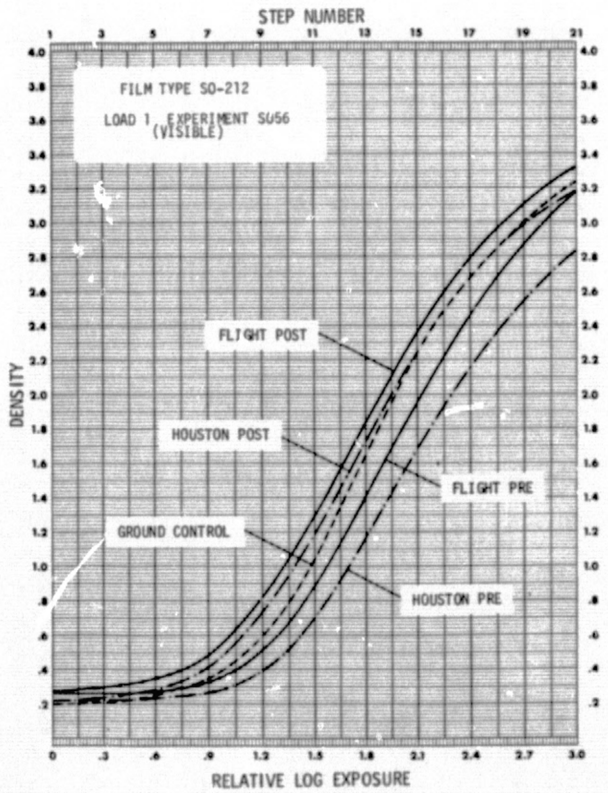
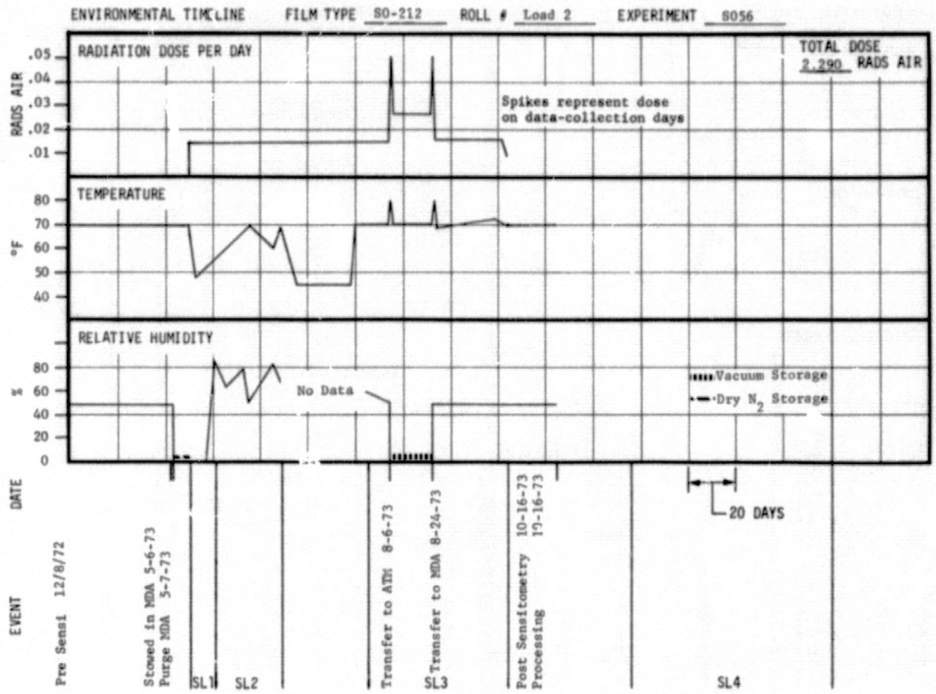


FIGURE D-29, FILM TYPE SO-212, LOAD I (S056)



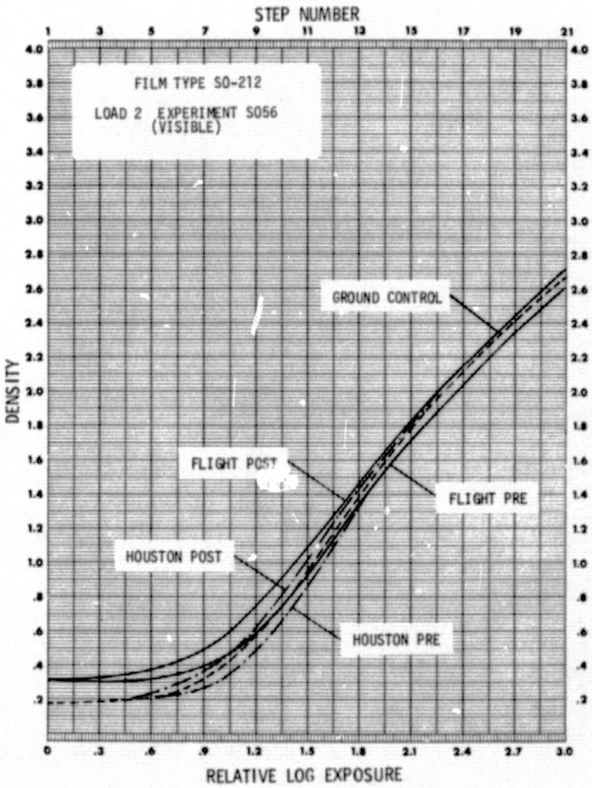
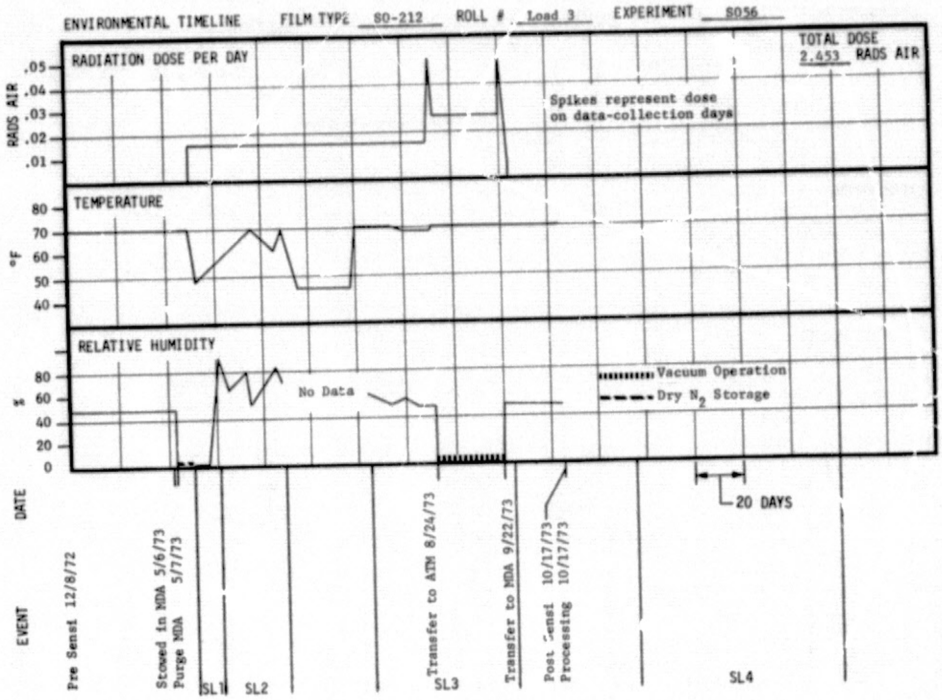


FIGURE D-30, FILM TYPE SO-212, LOAD 2 (S056)



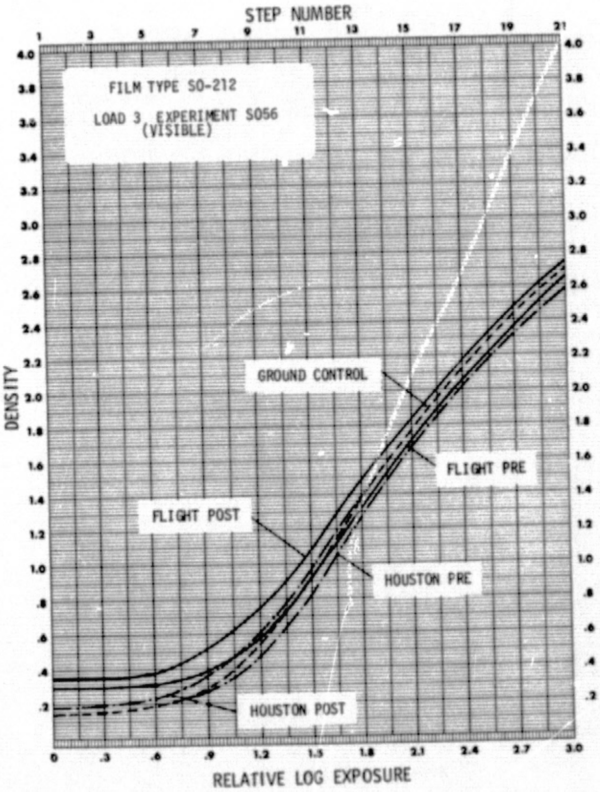
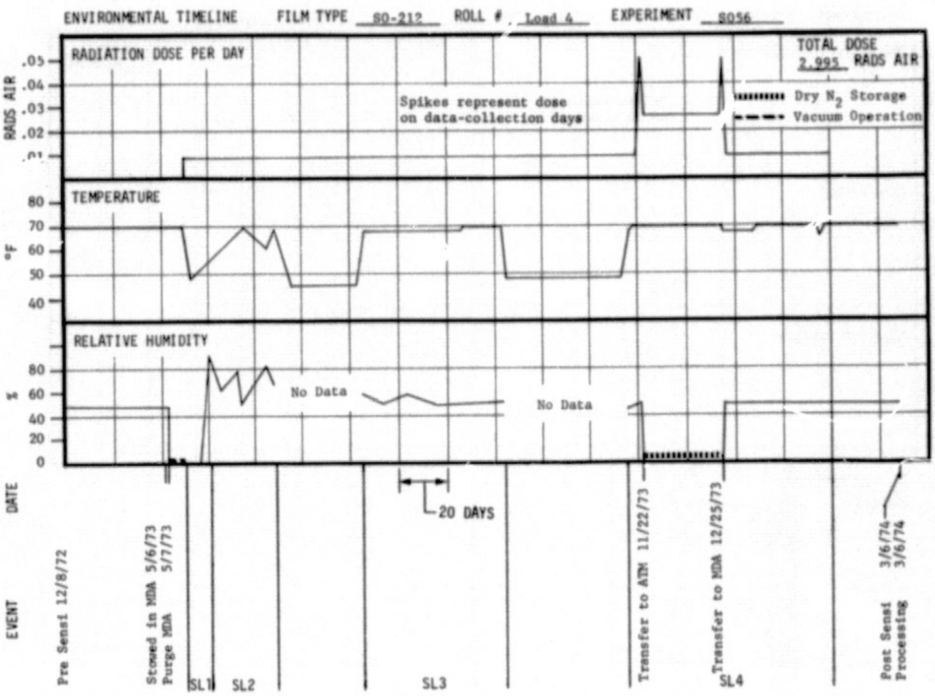


FIGURE D-31, FILM TYPE SO-212, LOAD 3 (S056)



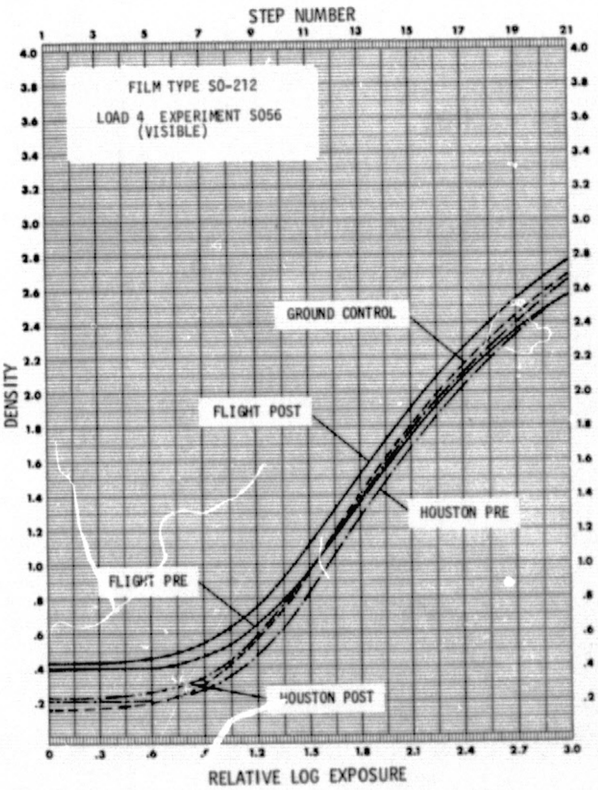
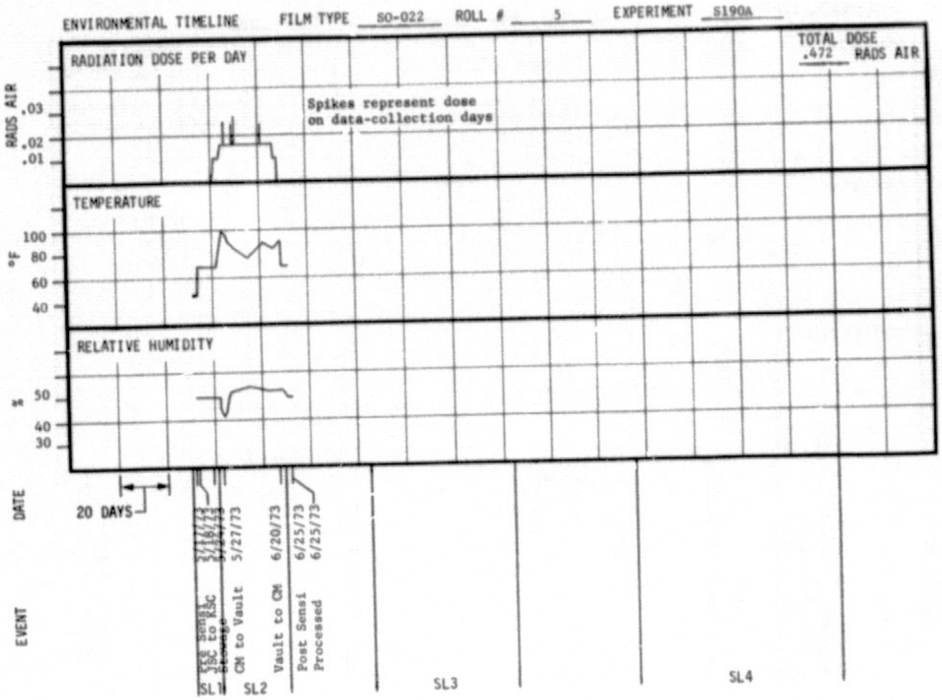


FIGURE D-32, FILM TYPE SO-212, LOAD 4 (SO56)



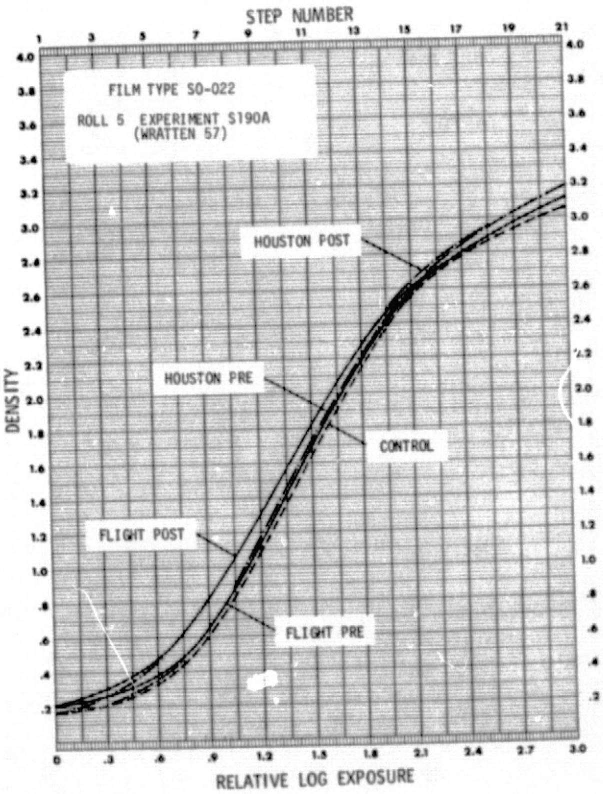
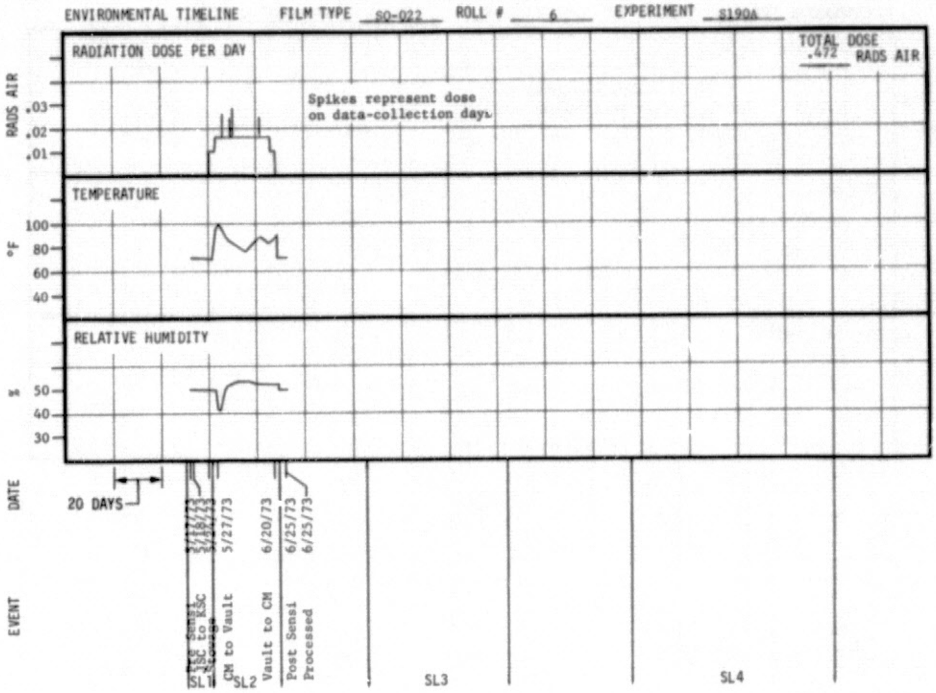


FIGURE D-33, FILM TYPE SO-022, ROLL 5



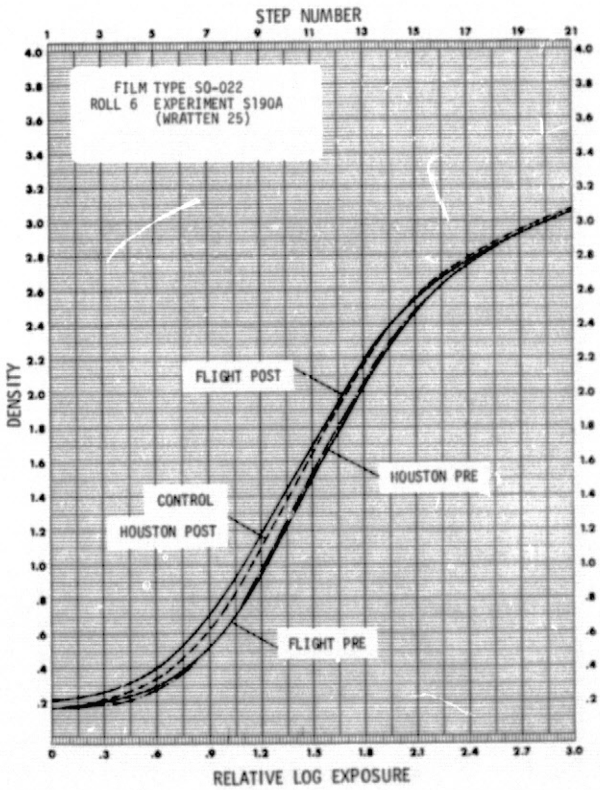
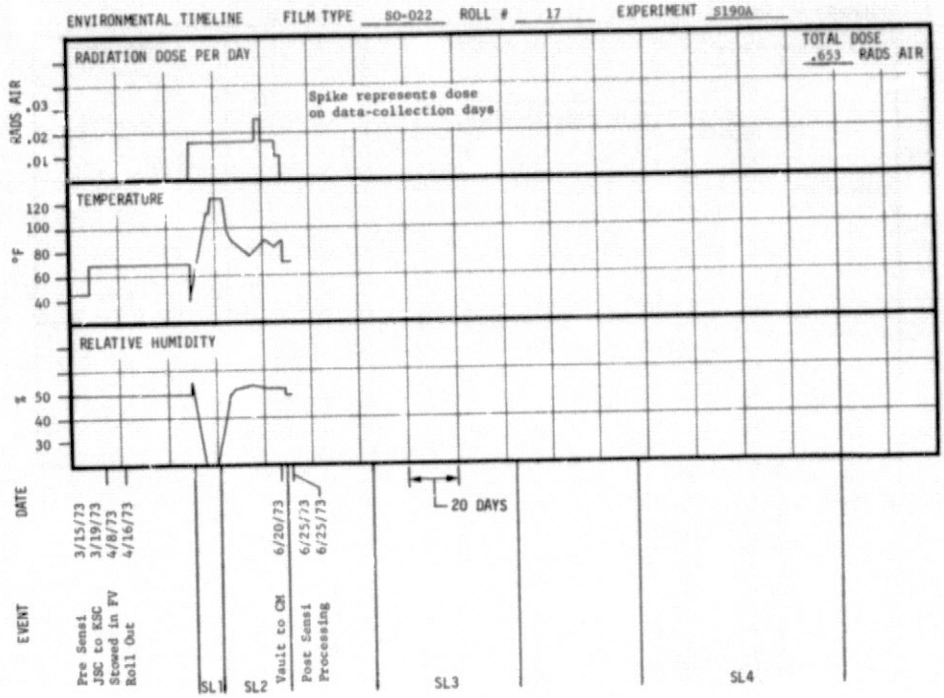


FIGURE D-34, FILM TYPE SO-022, ROLL 6



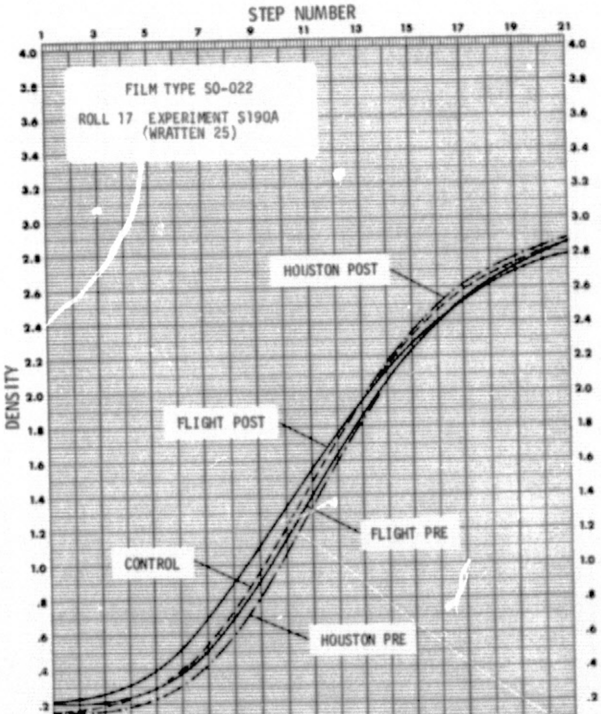
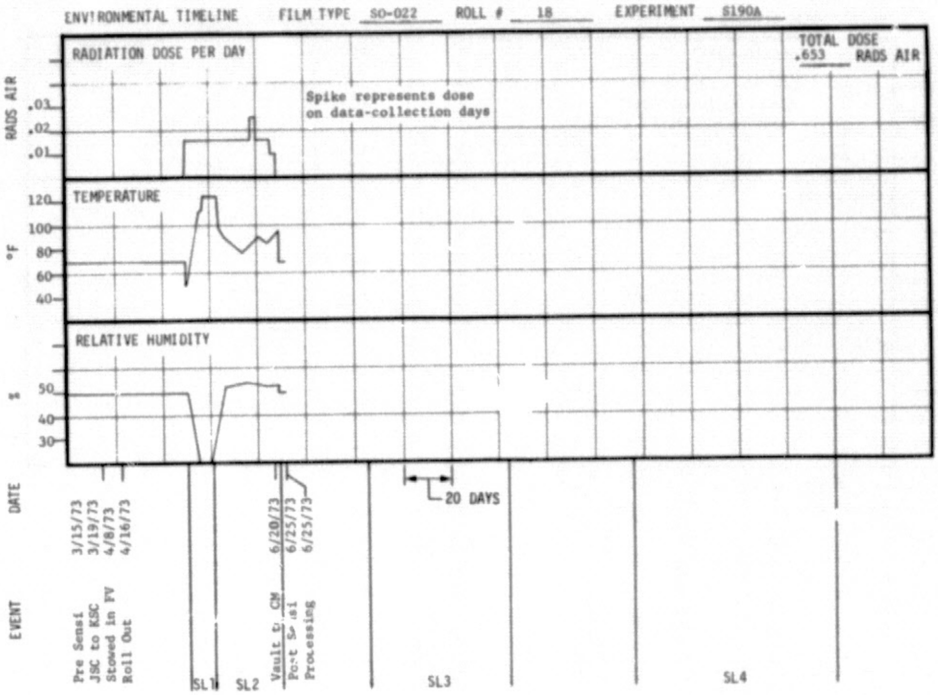


FIGURE D-35, FILM TYPE SO-022, ROLL 17



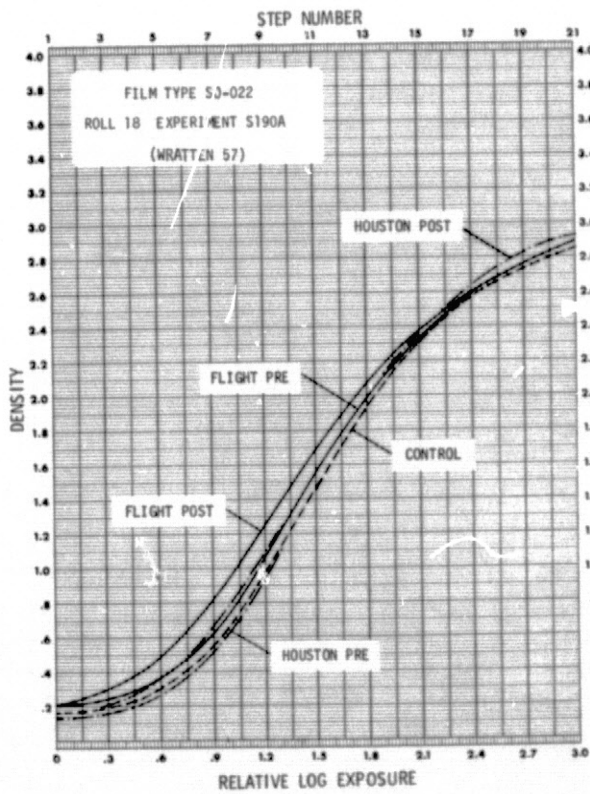
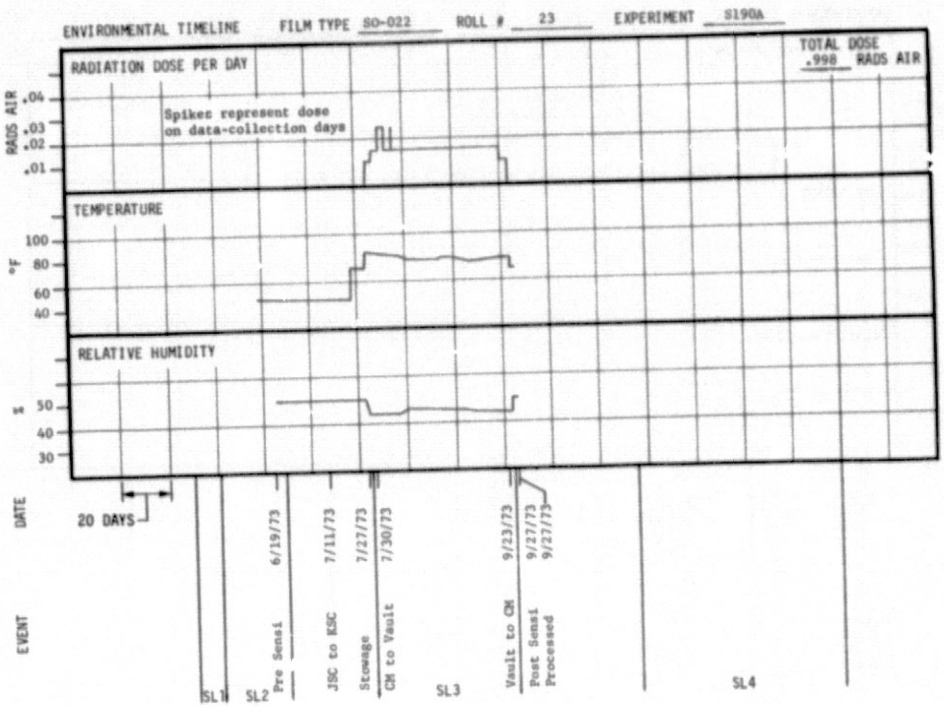


FIGURE D-36, FILM TYPE SO-022, ROLL 18



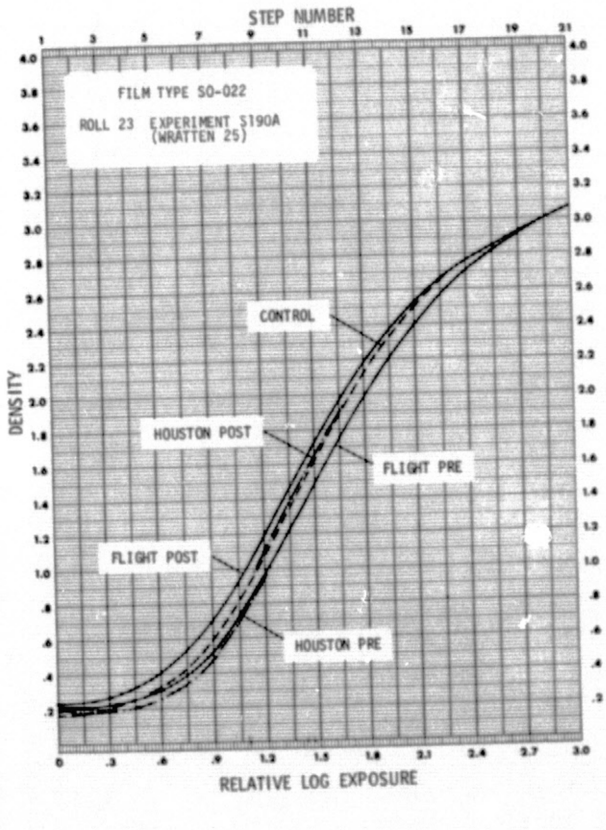
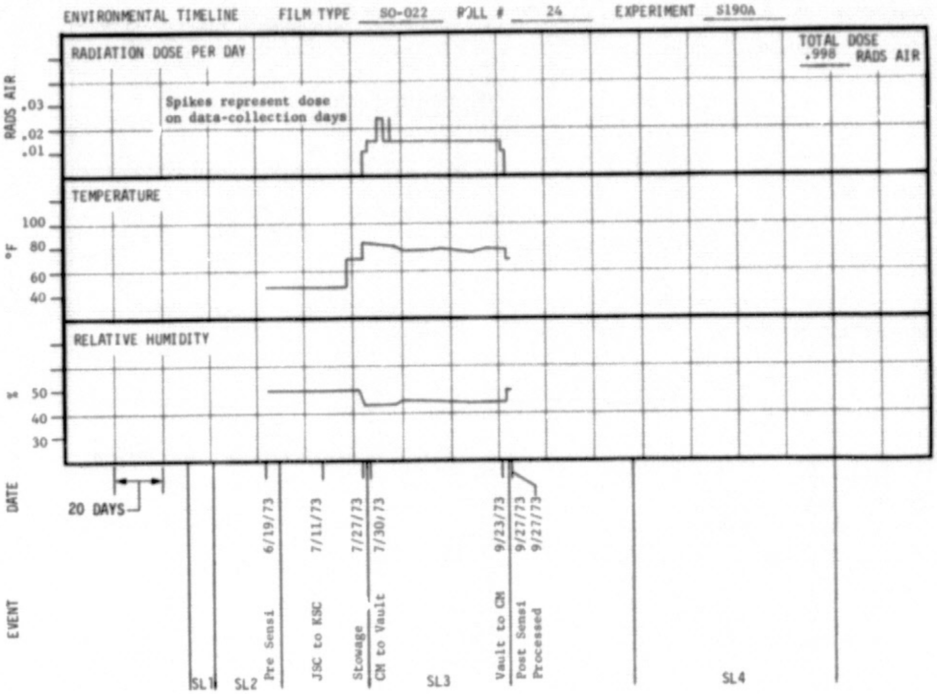


FIGURE D-37. FILM TYPE SO-022, ROLL 23



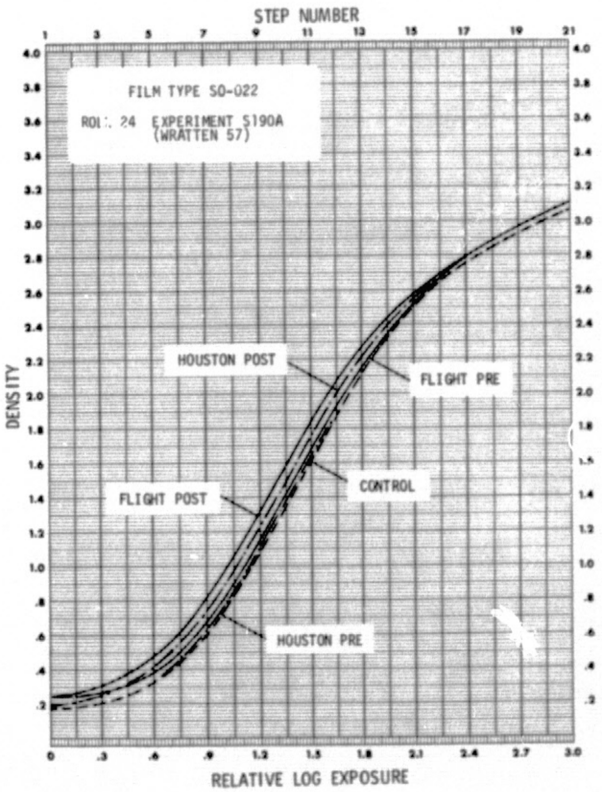
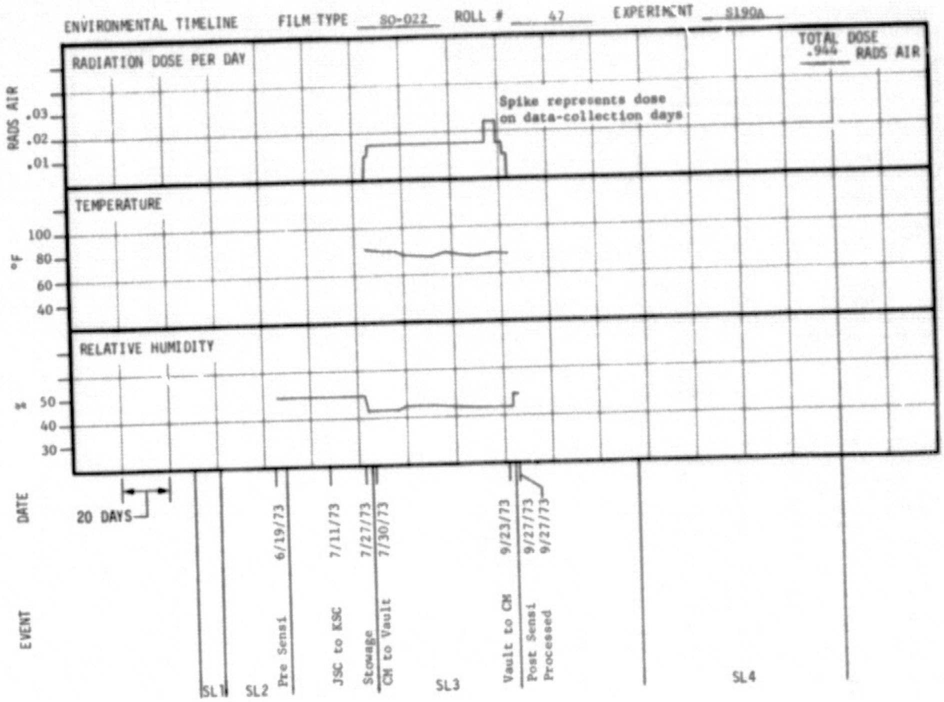


FIGURE D-38. FILM TYPE SO-022, ROLL 24



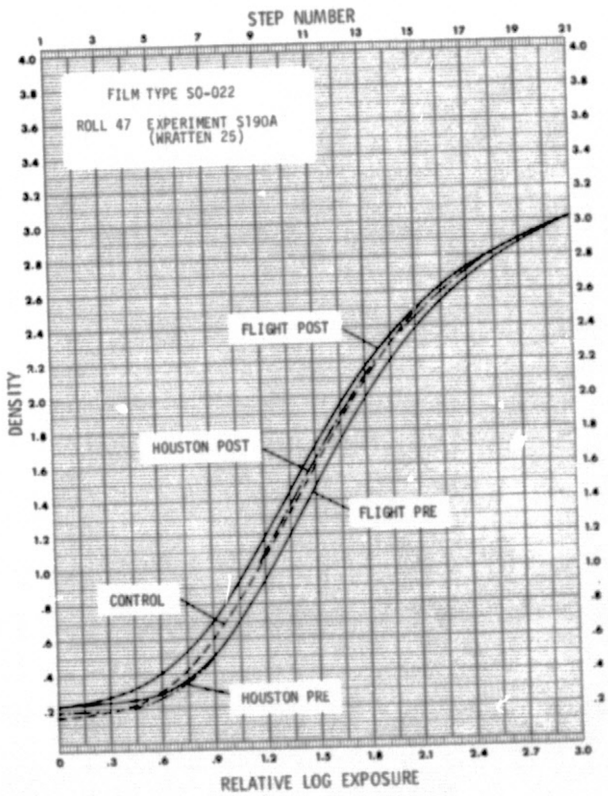
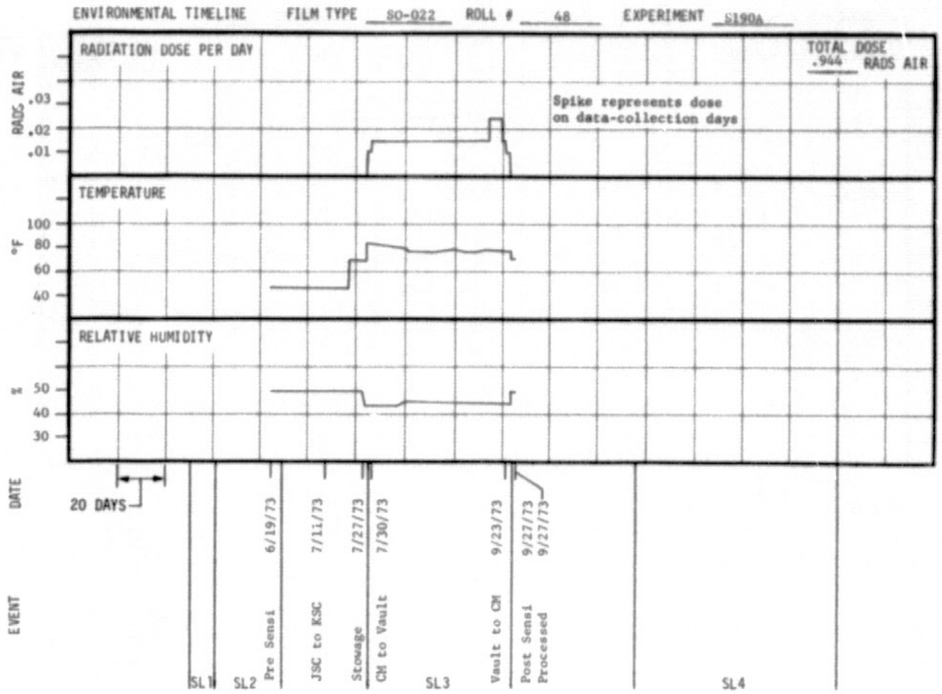


FIGURE D-39, FILM TYPE SO-022, ROLL 47



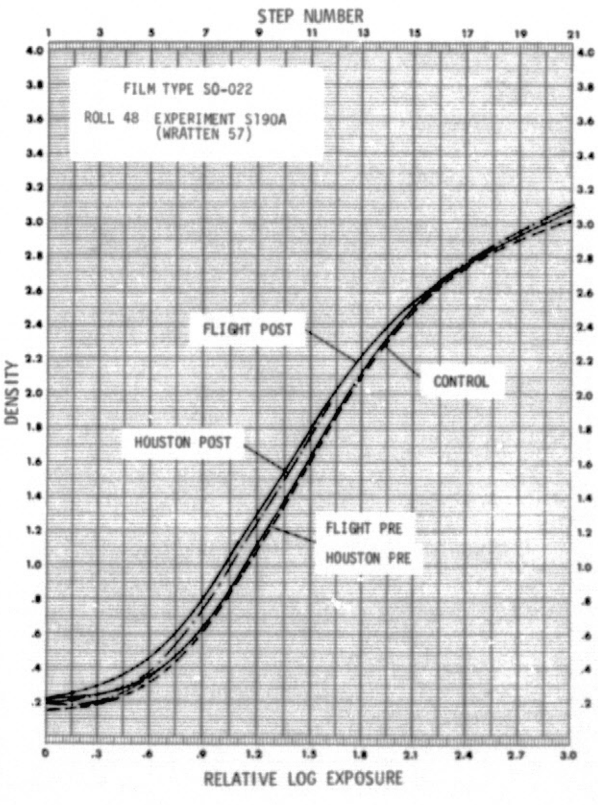
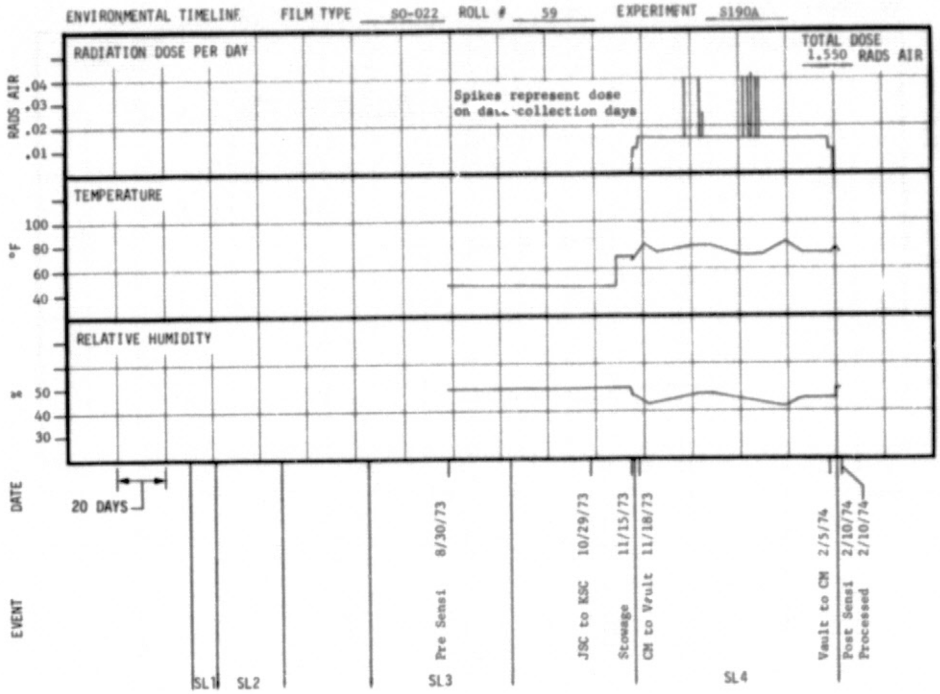


FIGURE D-40, FILM TYPE SO-022, ROLL 48



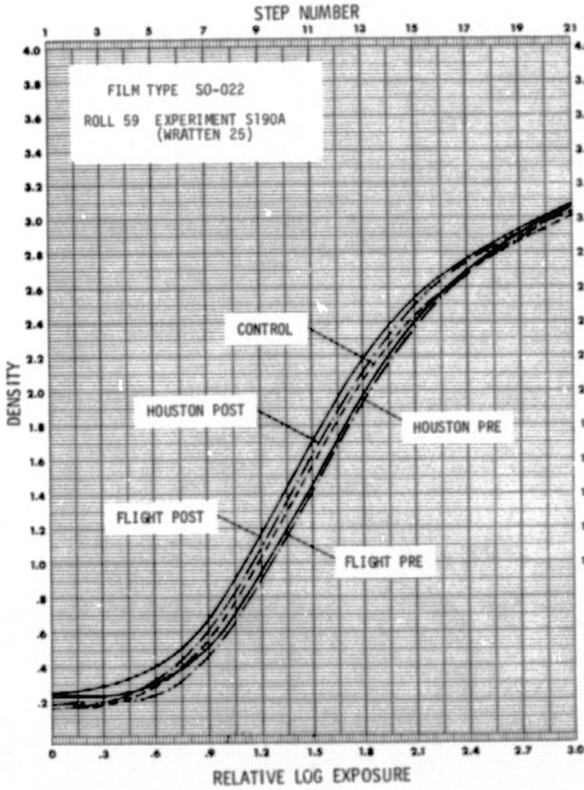
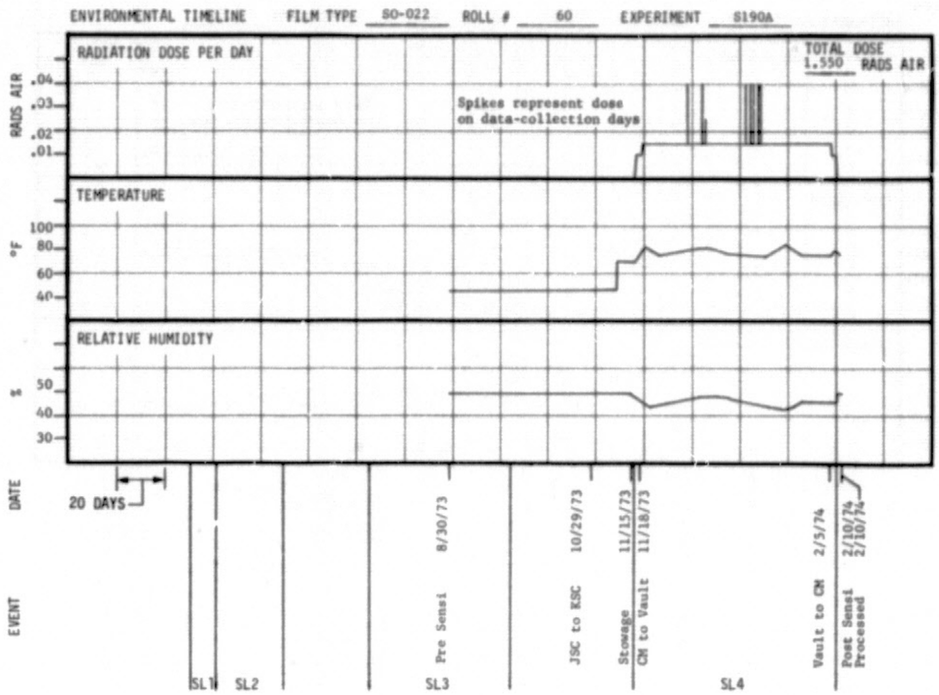


FIGURE D-41, FILM TYPE SO-022, ROLL 59



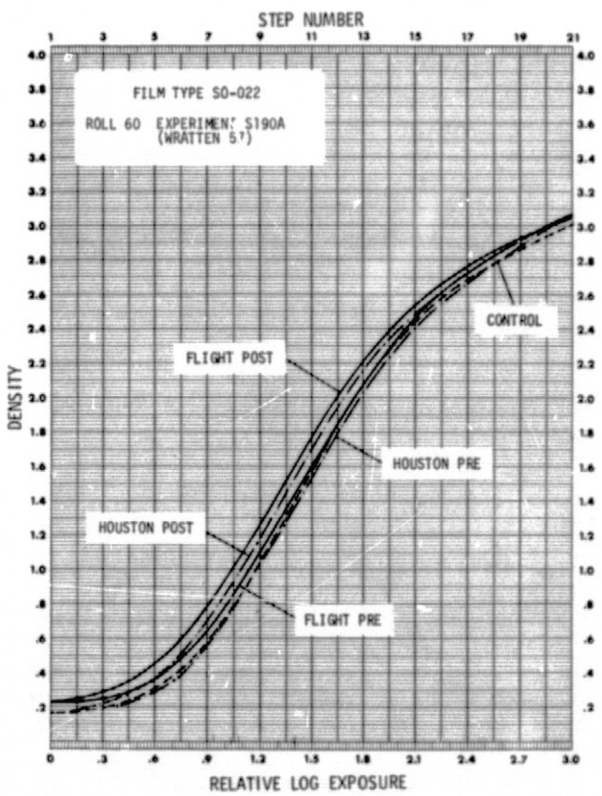
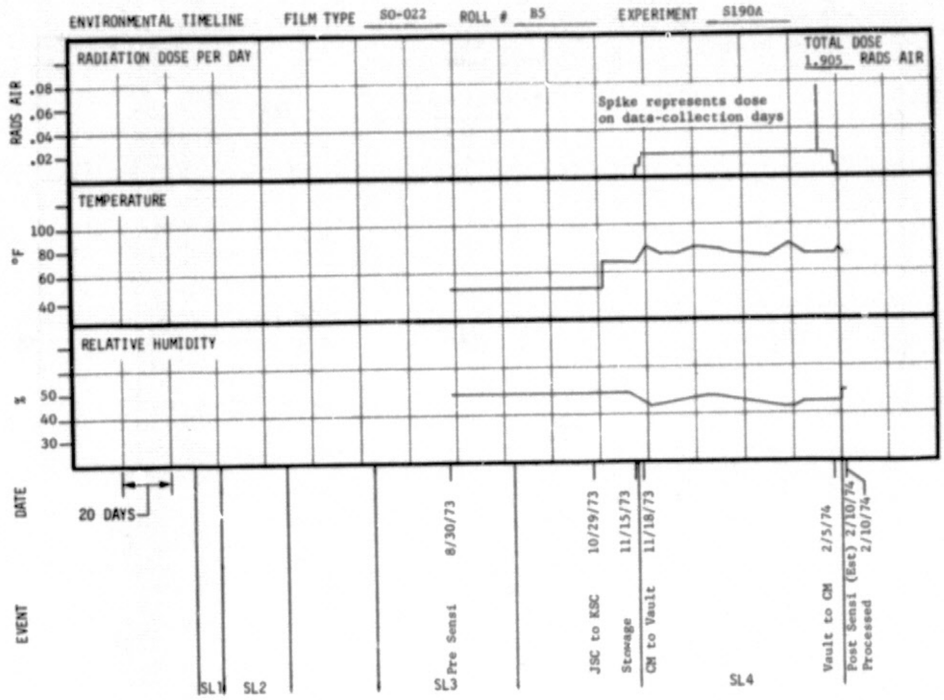


FIGURE D-42, FILM TYPE SO-022, ROLL 60



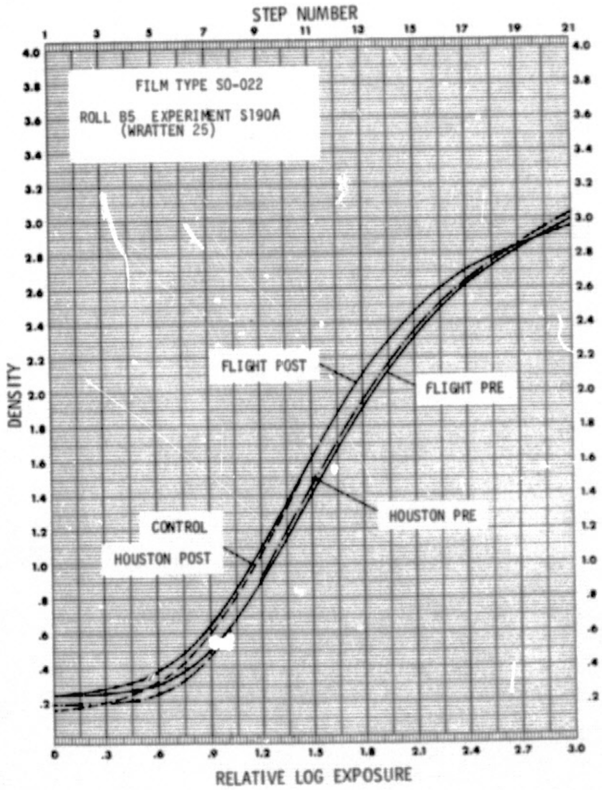
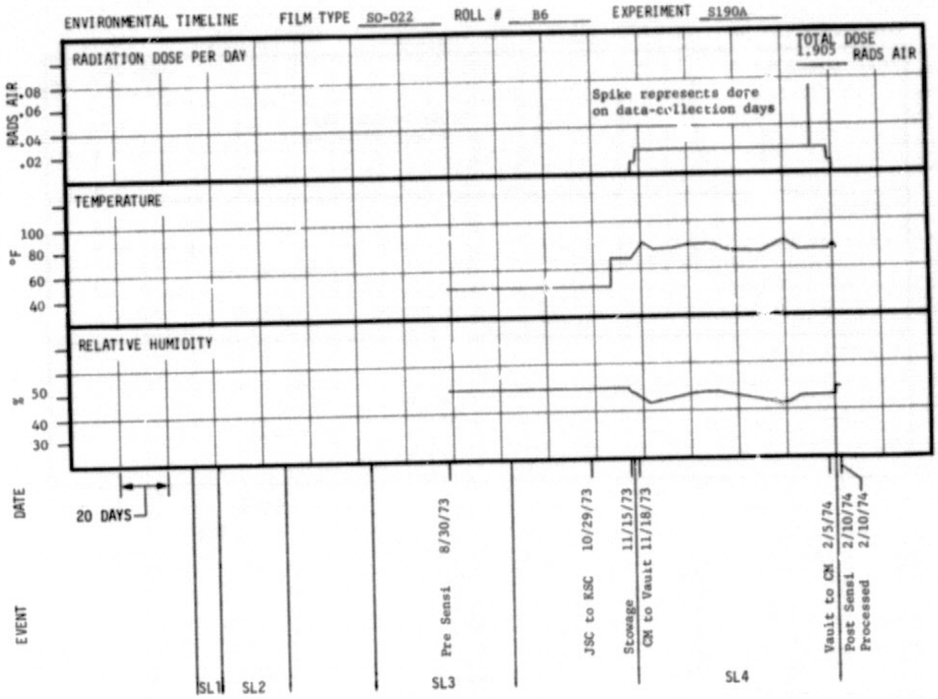


FIGURE D-43, FILM TYPE SO-022, ROLL B5



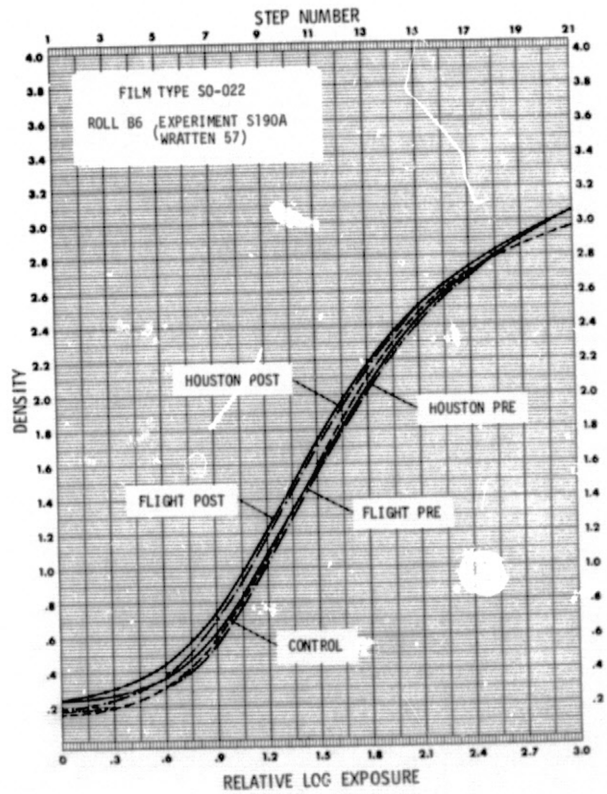
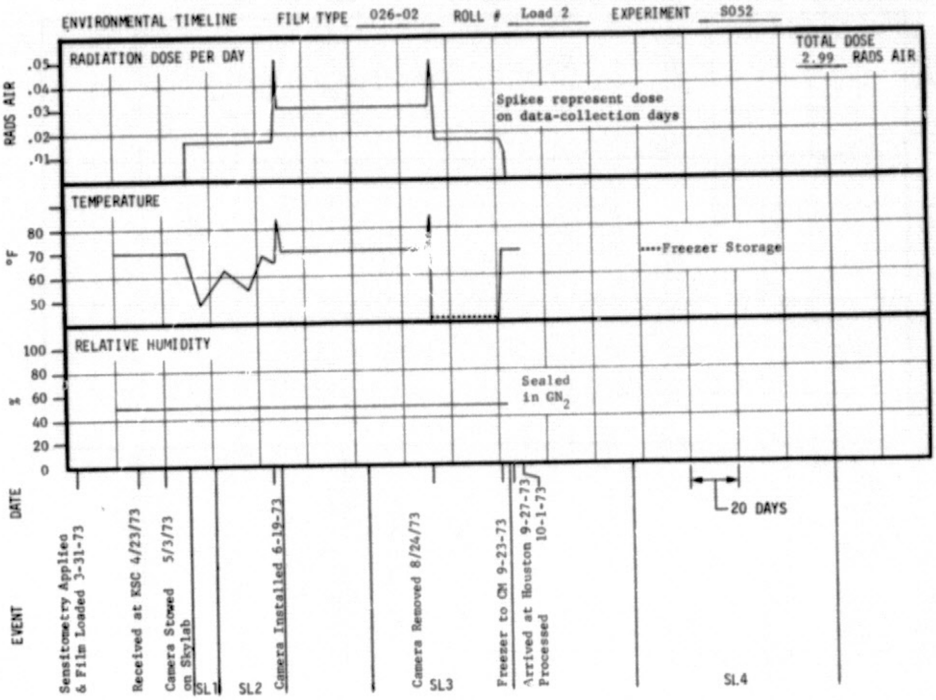


FIGURE D-44, FILM TYPE SO-022, ROLL B6



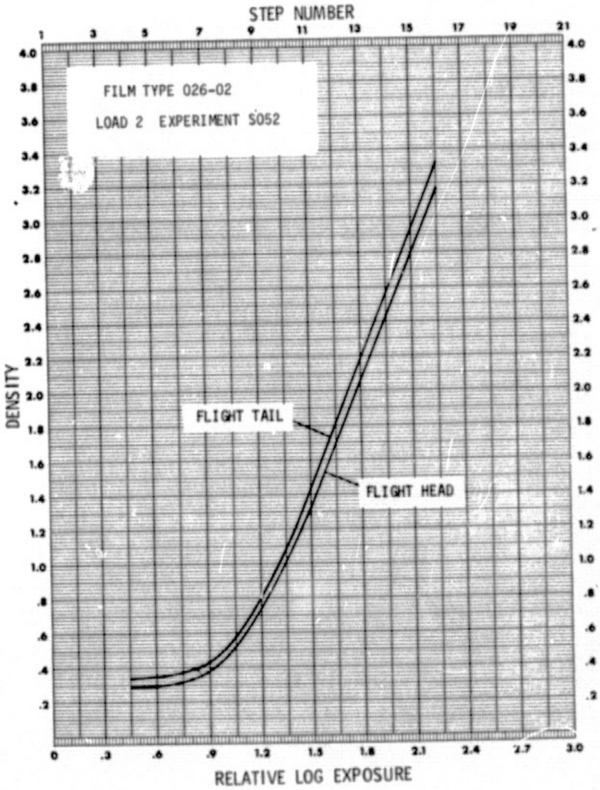
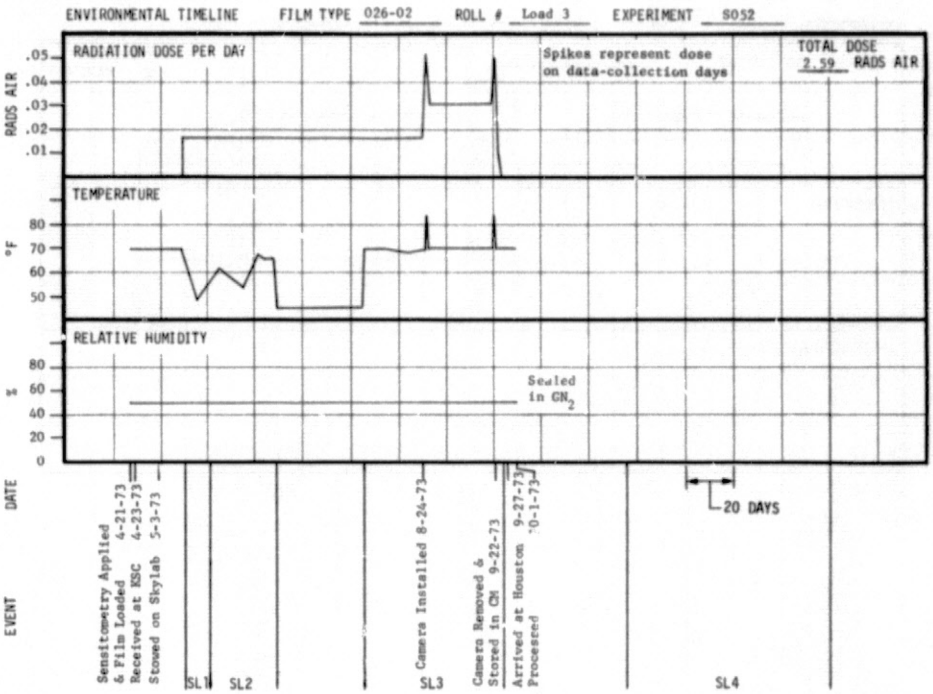


FIGURE D-45, FILM TYPE 026-02, LOAD 2



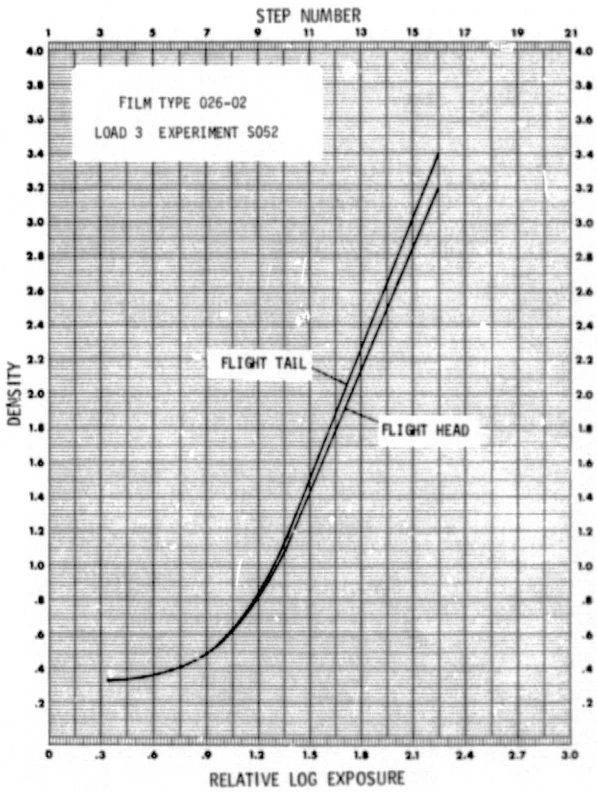
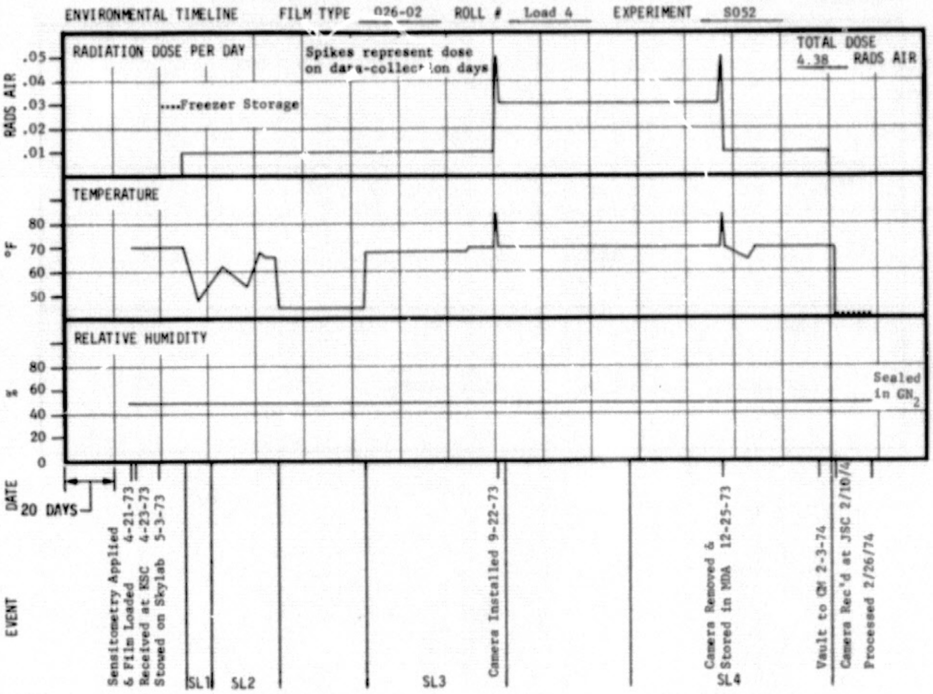


FIGURE D-46, FILM TYPE 026-02, LOAD 3



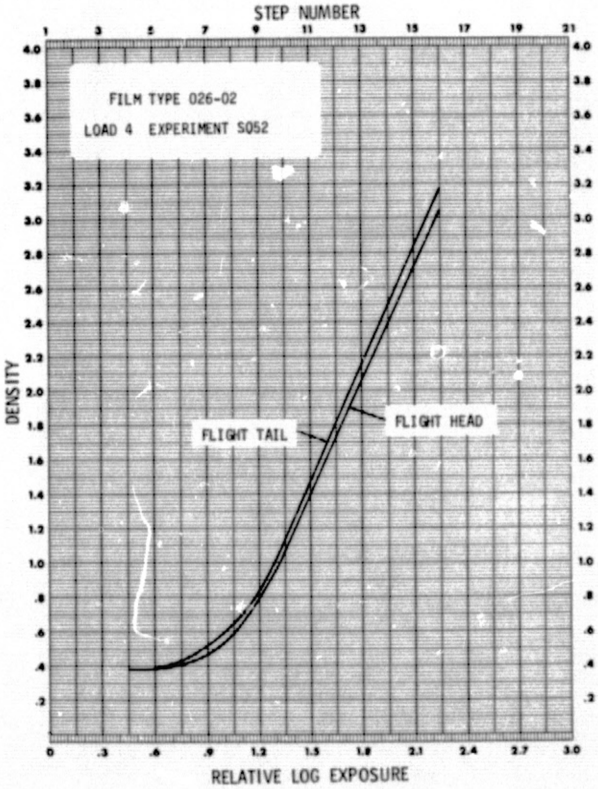
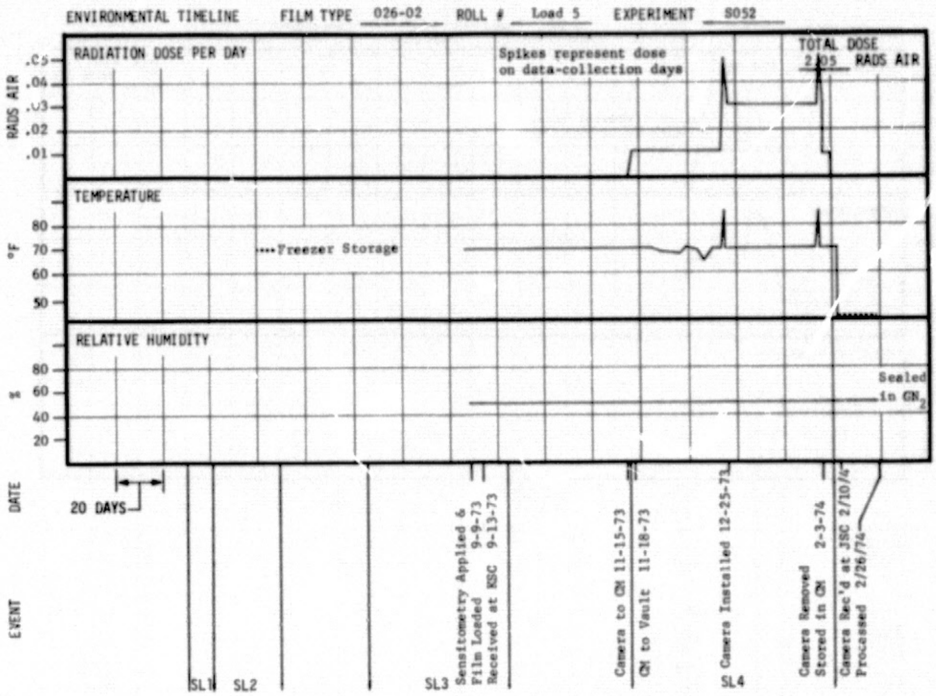


FIGURE D-47, FILM TYPE 026-02, LOAD 4



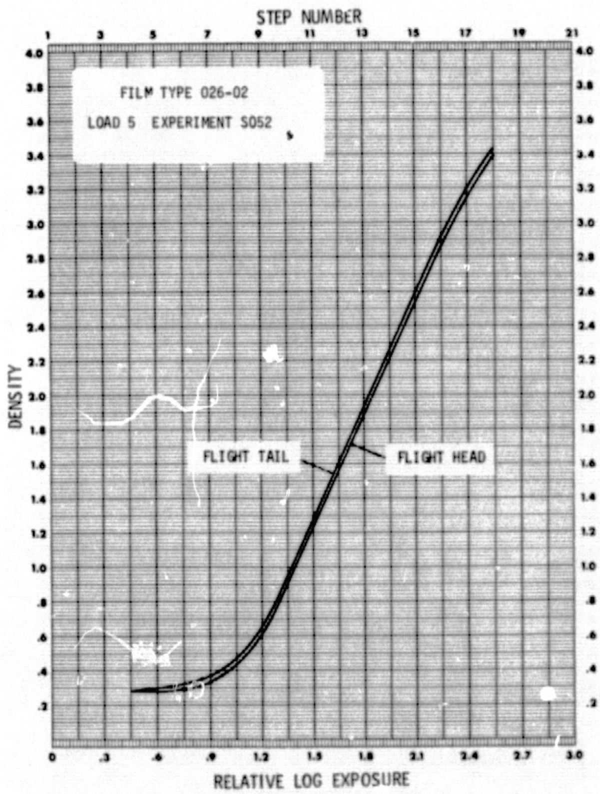
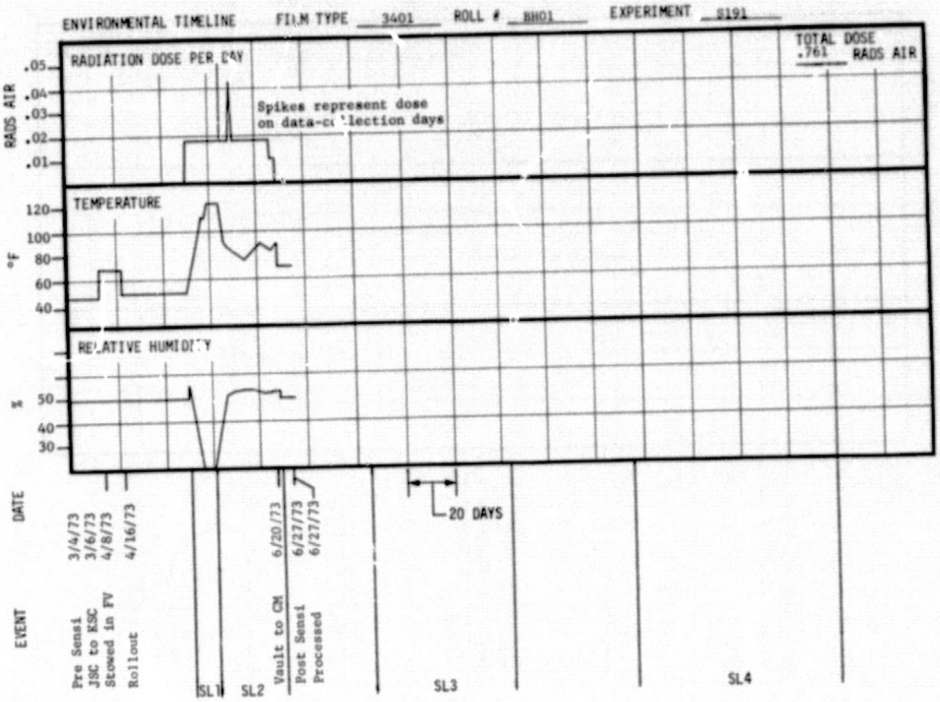


FIGURE D-48, FILM TYPE 026-02, LOAD 5



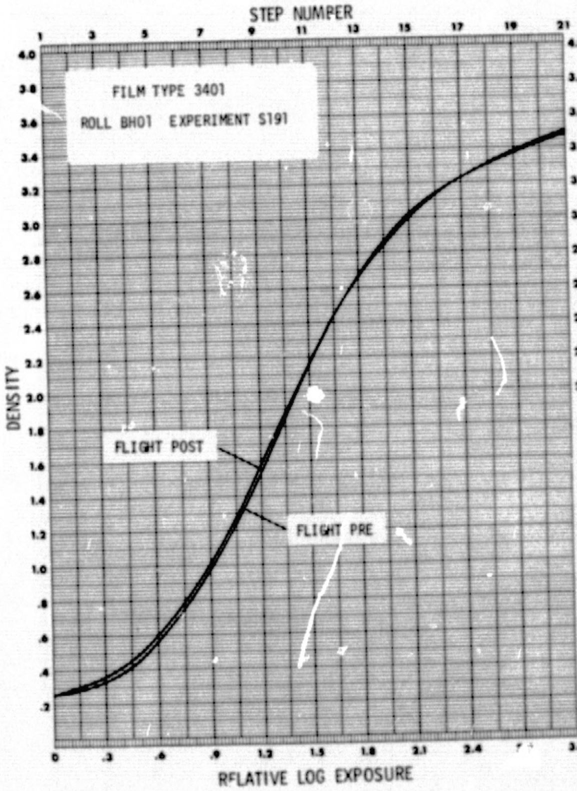
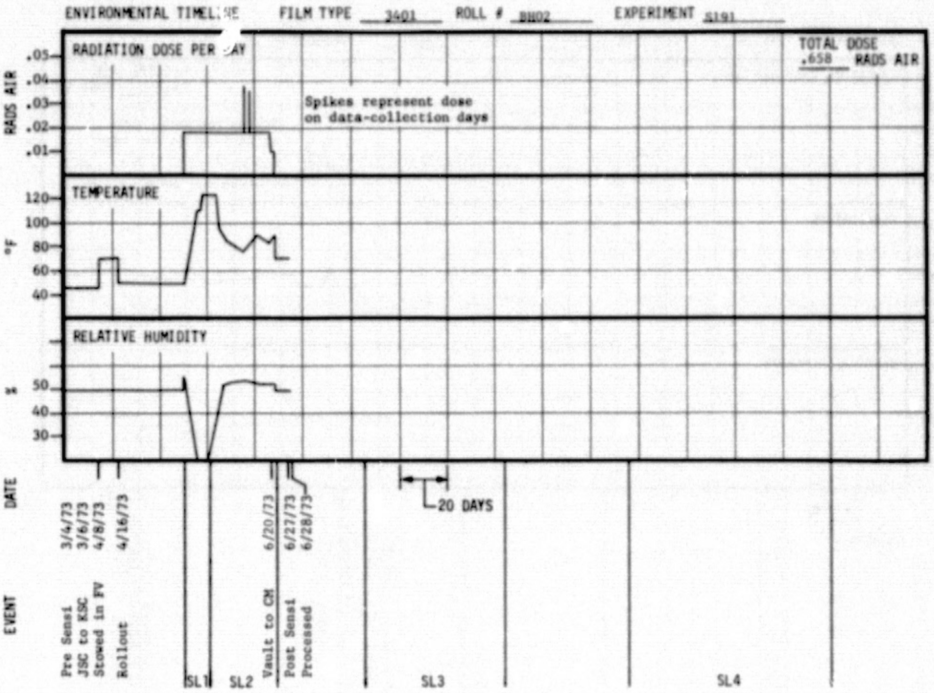


FIGURE D-49, FILM TYPE 3401, ROLL BH01



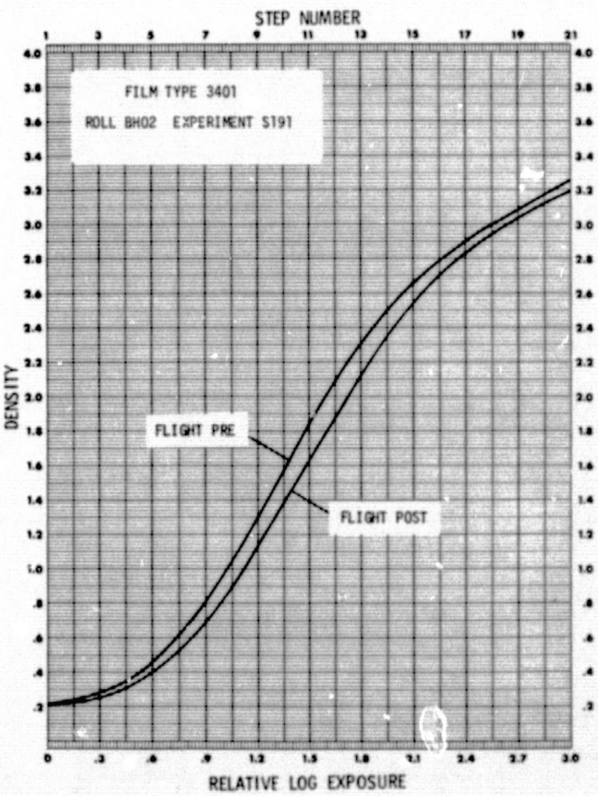
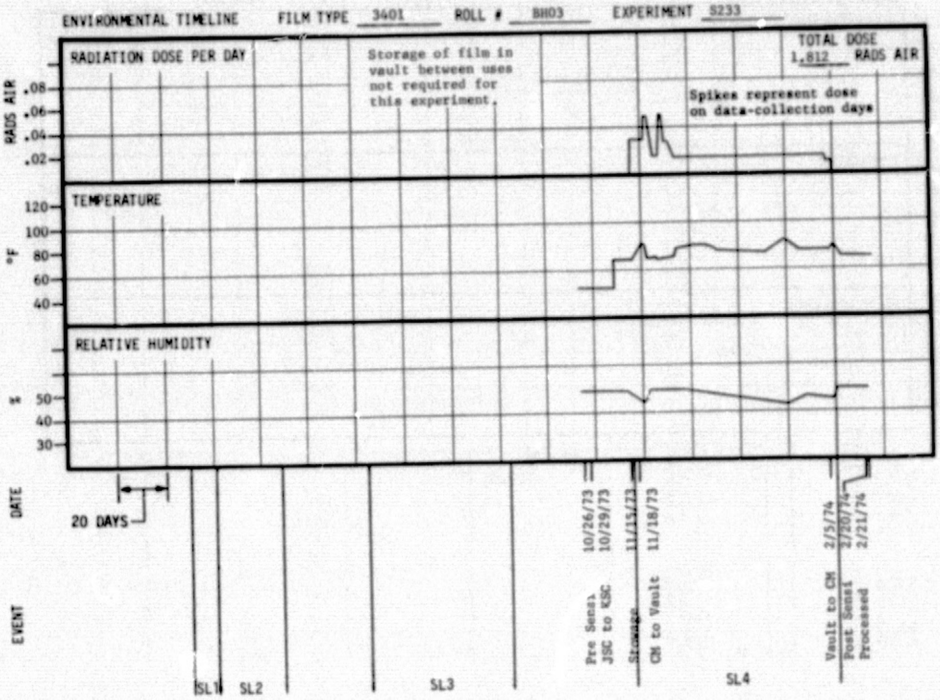


FIGURE D-50, FILM TYPE 3401, ROLL BH02



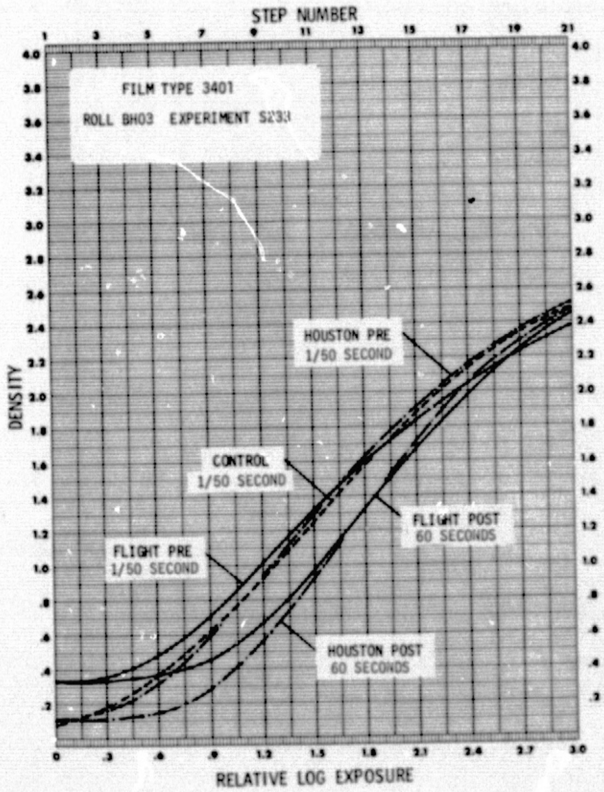
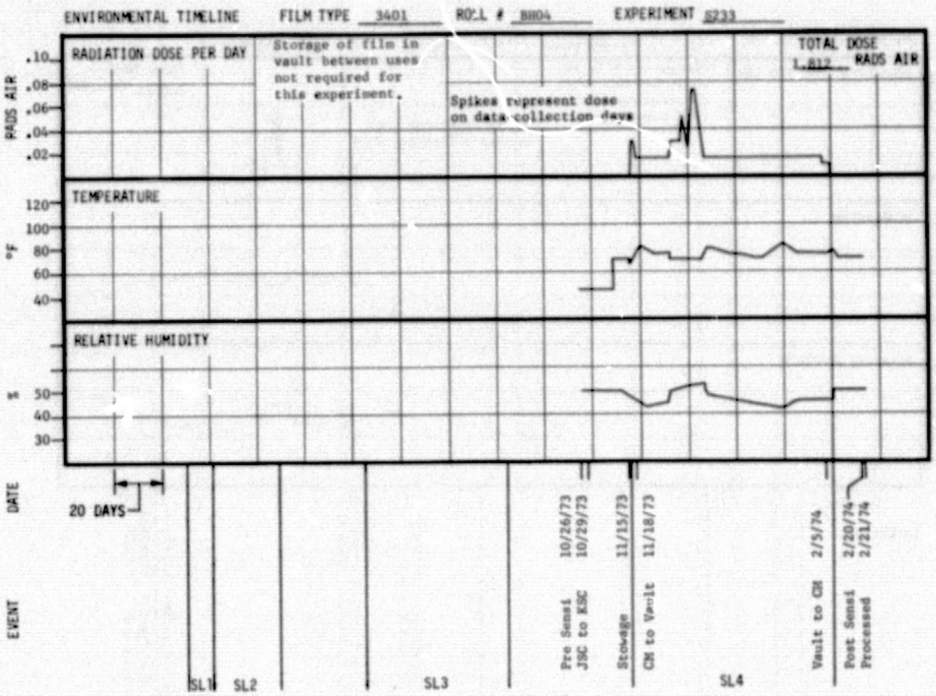


FIGURE D-51, FILM TYPE 3401, ROLL BH03



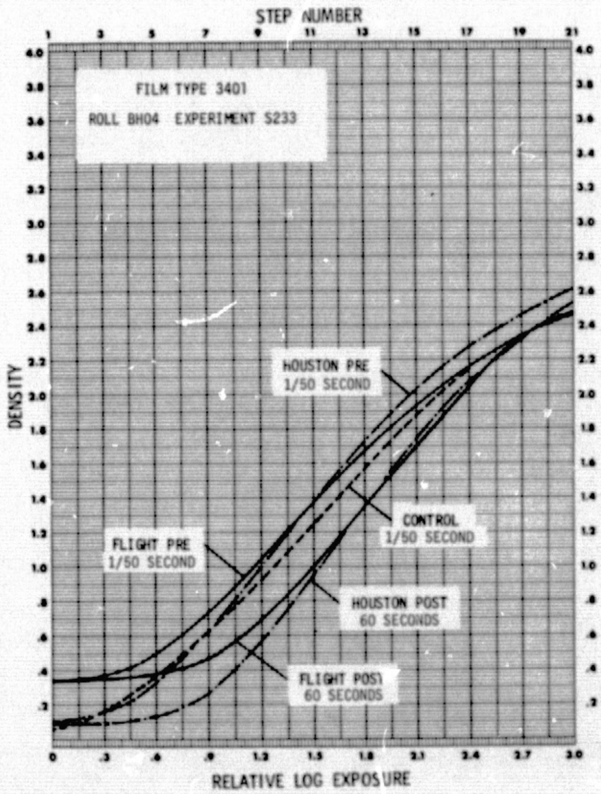
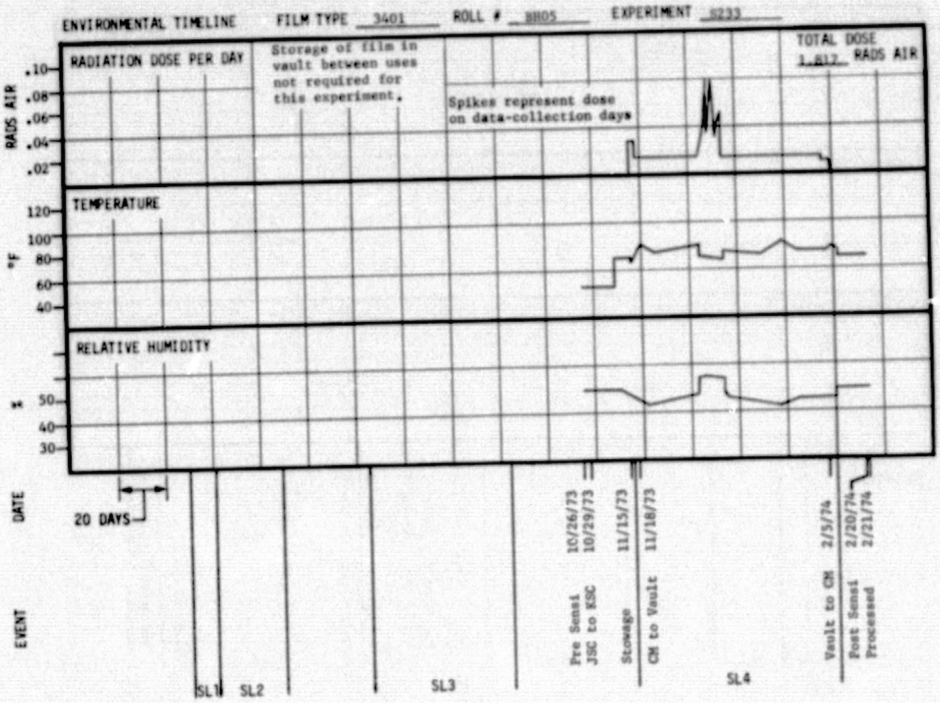


FIGURE D-52, FILM TYPE 3401, ROLL BH04



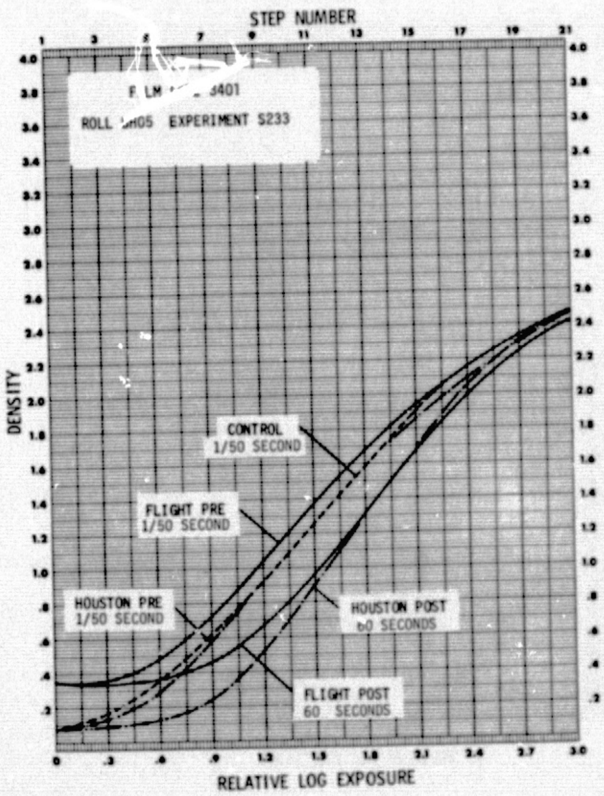
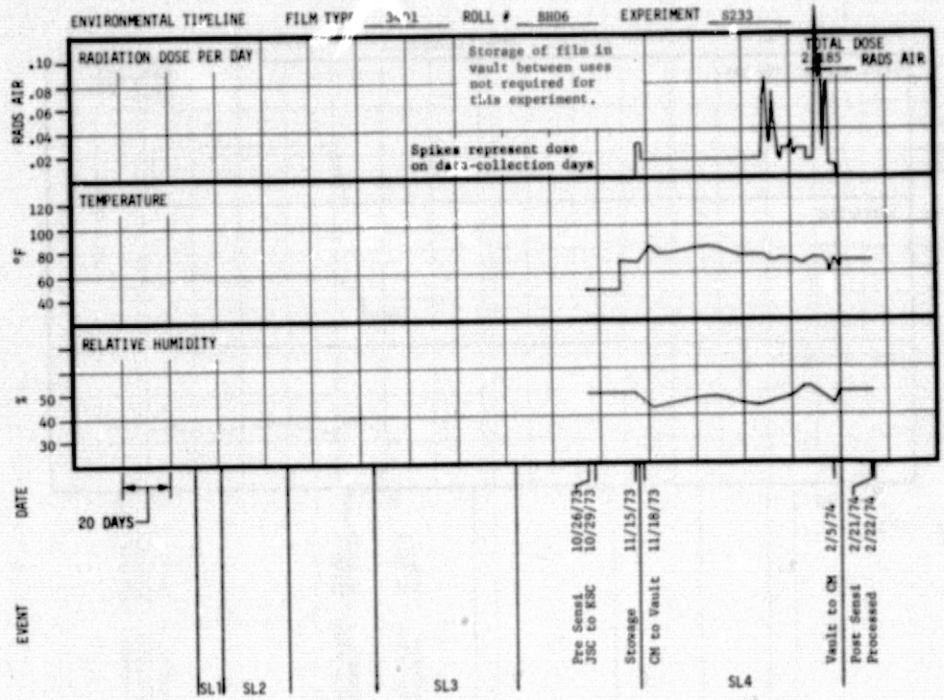


FIGURE D-53, FILM TYPE 3401, ROLL BH05



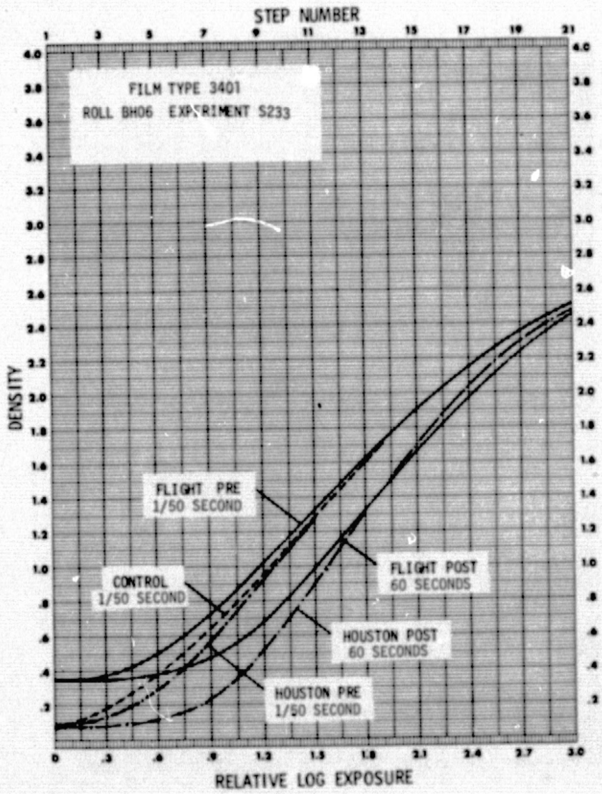
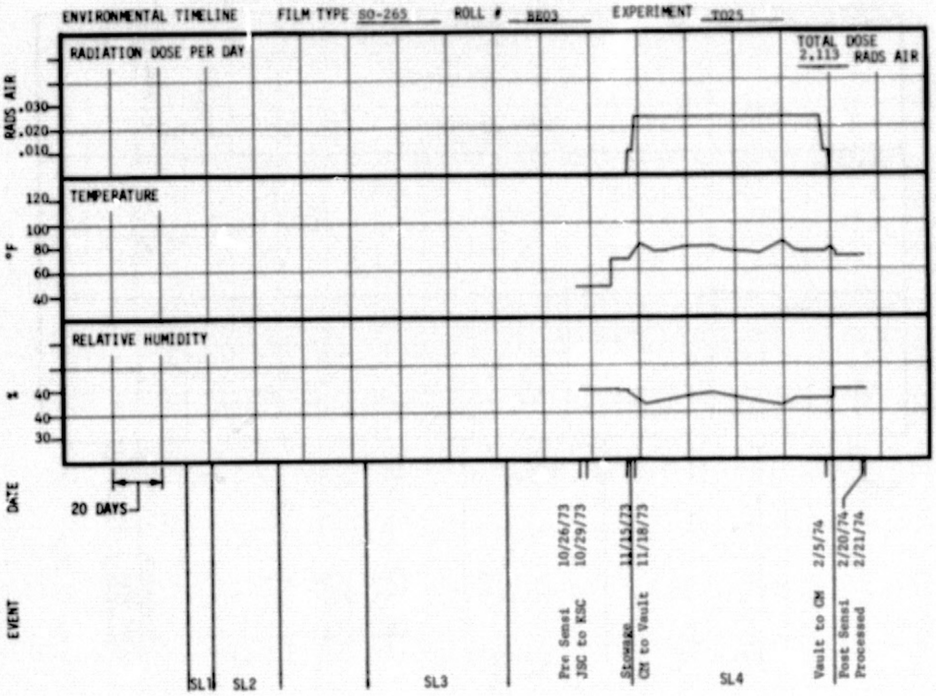


FIGURE D-54, FILM TYPE 3401, ROLL BH06



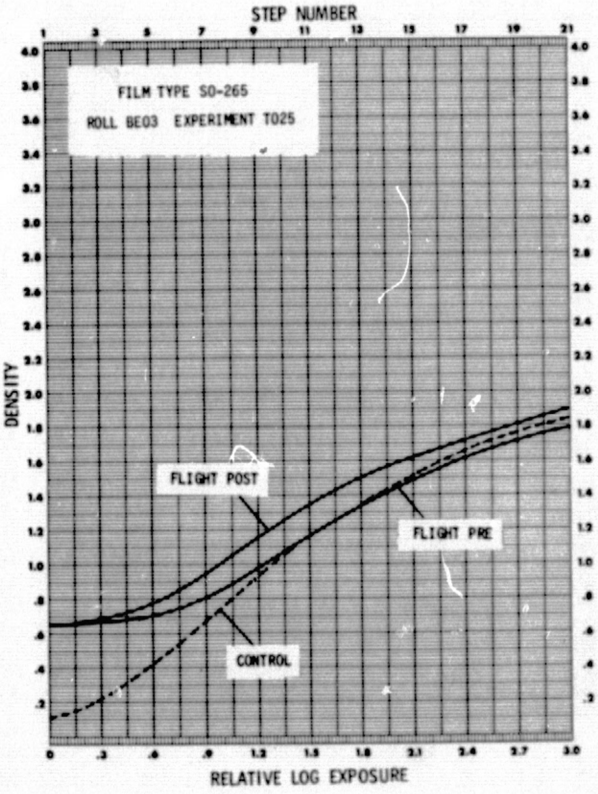
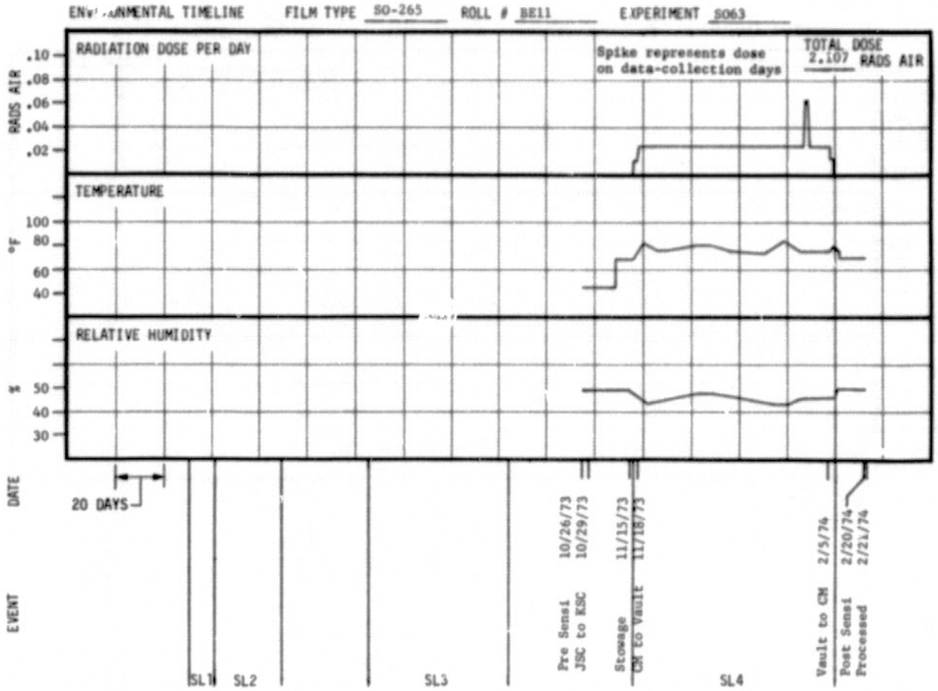


FIGURE D-55, FILM TYPE SO-265, ROLL BE03



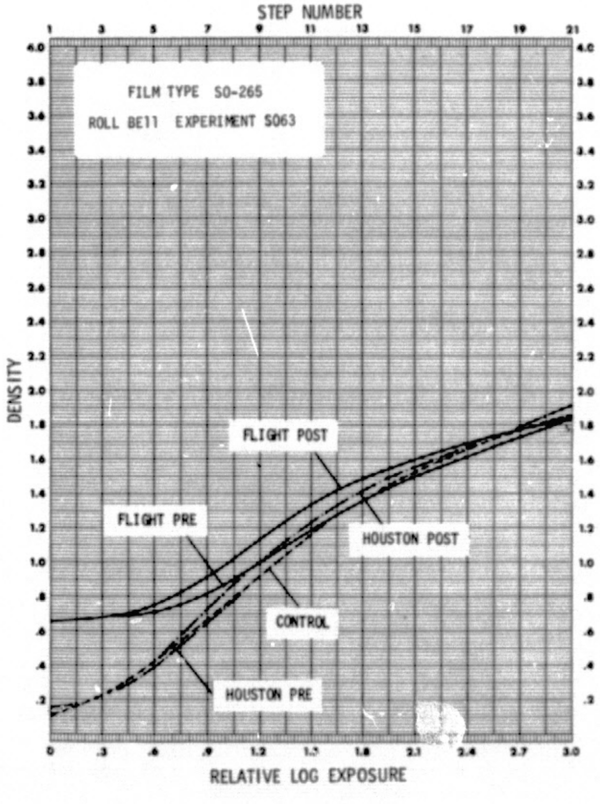
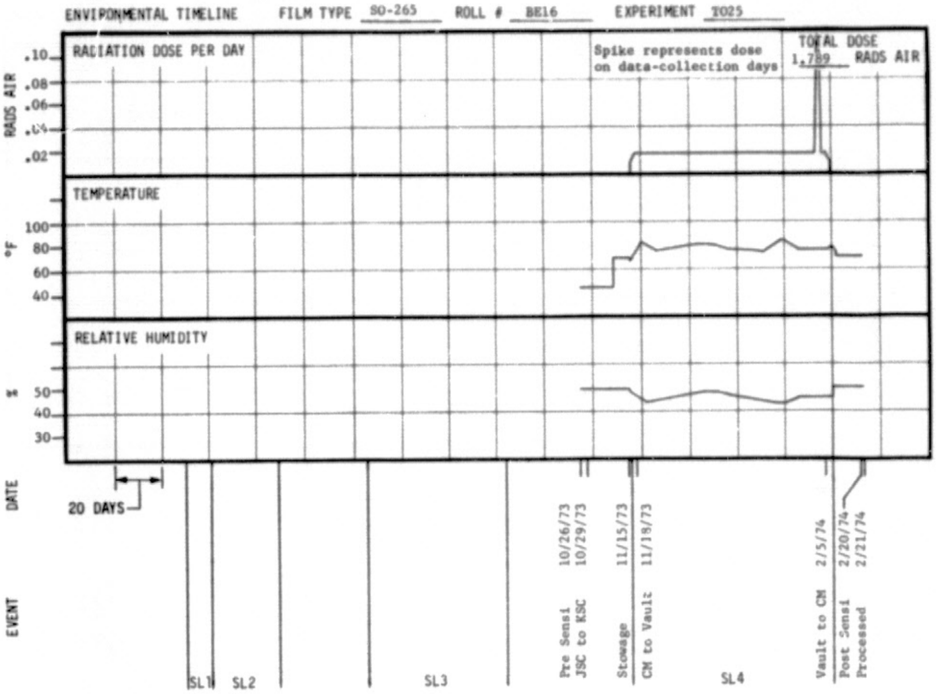


FIGURE D-56, FILM TYPE SO-265, ROLL BE11



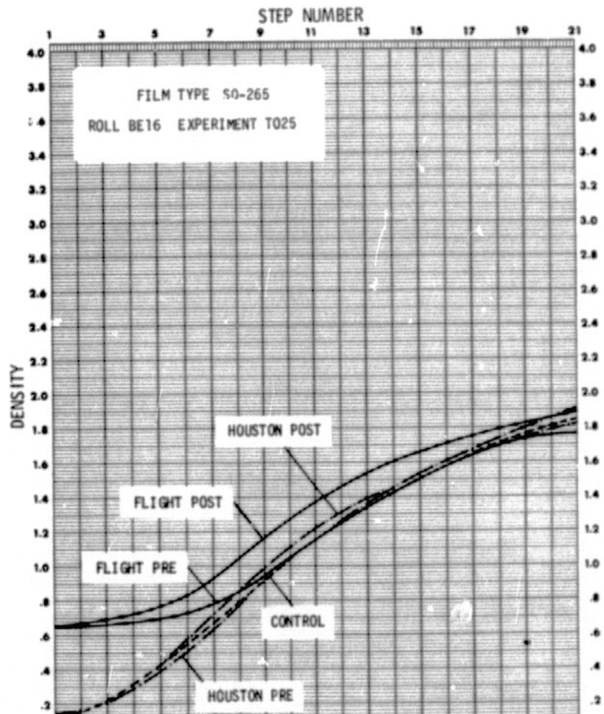
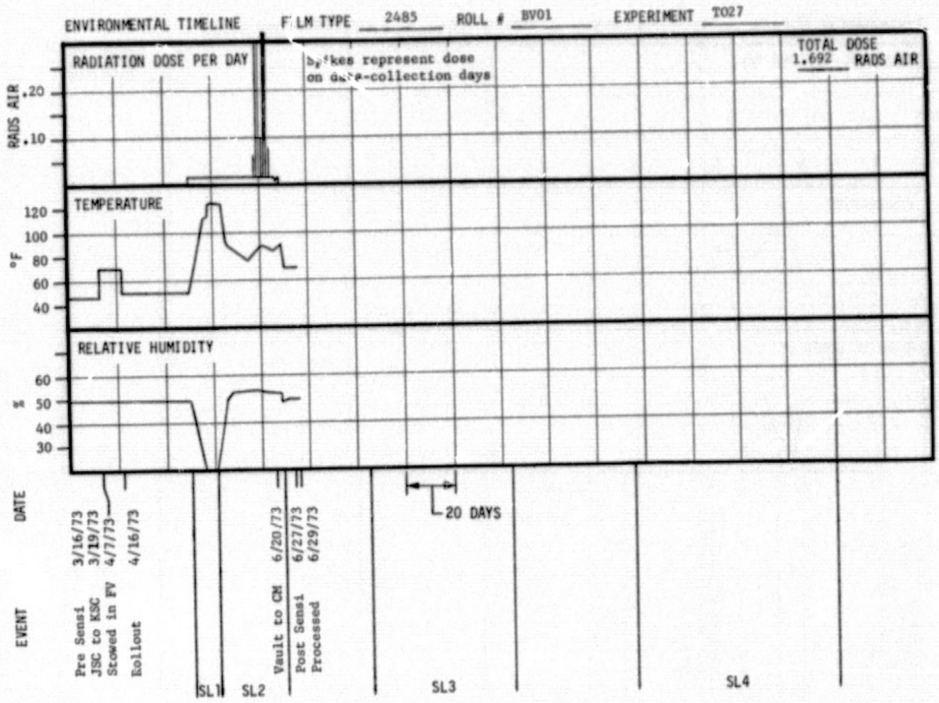


FIGURE D-57, FILM TYPE SO-265, ROLL BE16



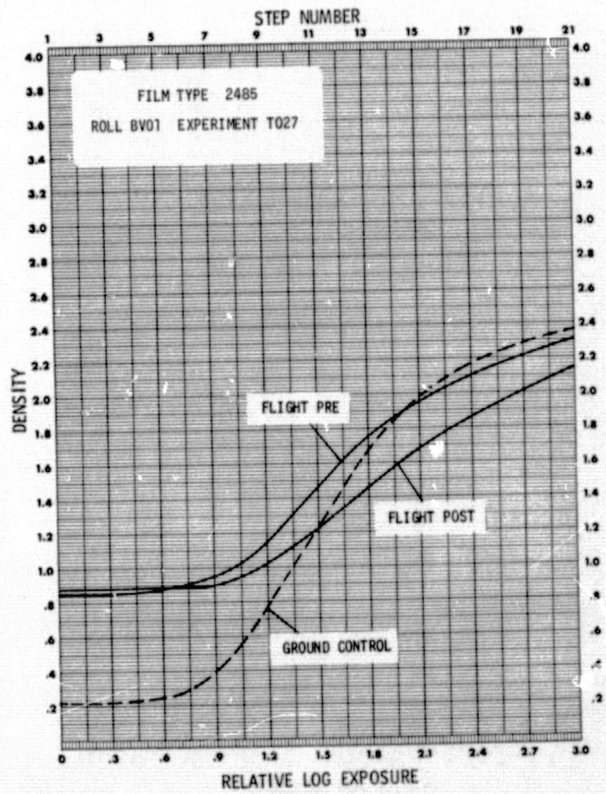
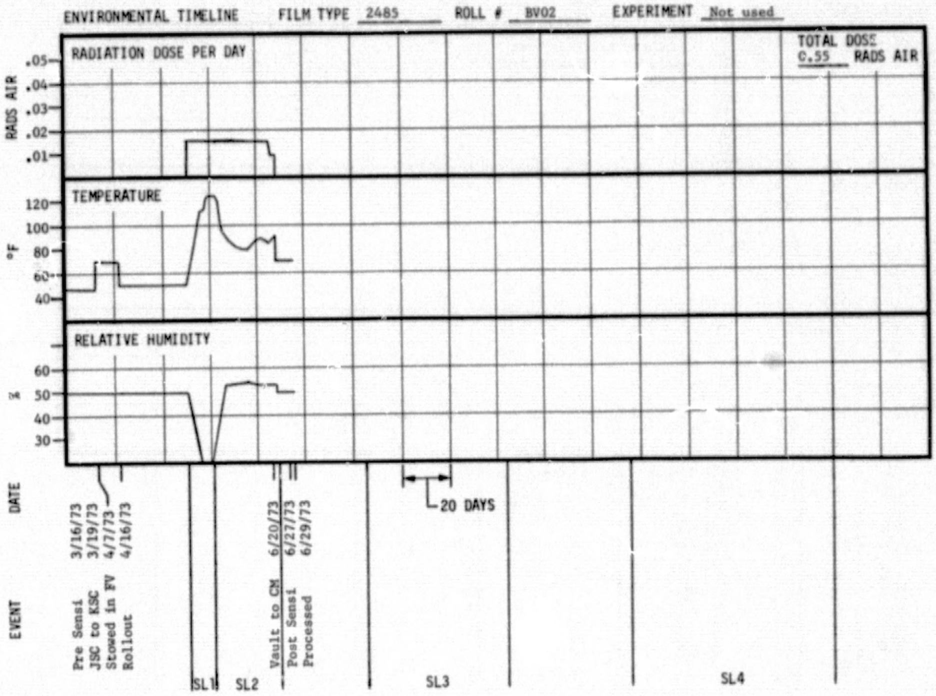


FIGURE D-58, FILM TYPE 2485, ROLL BV01

C-3



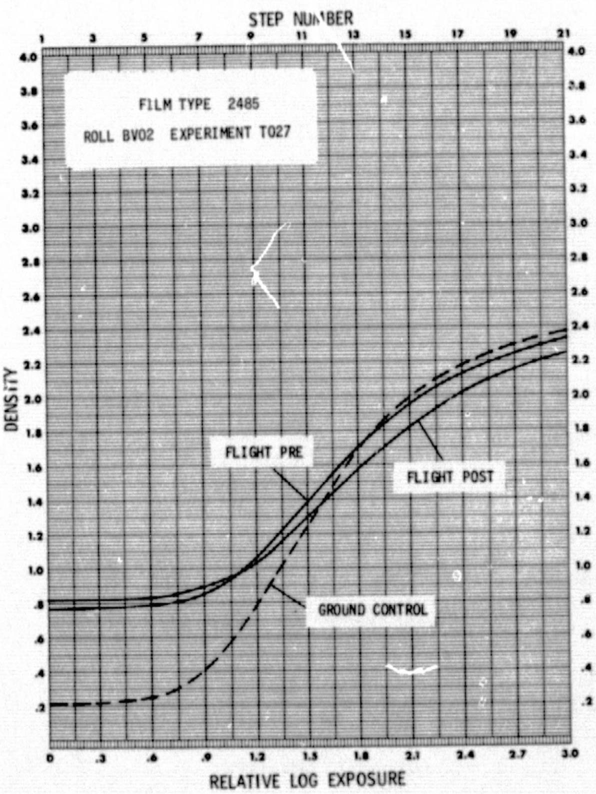
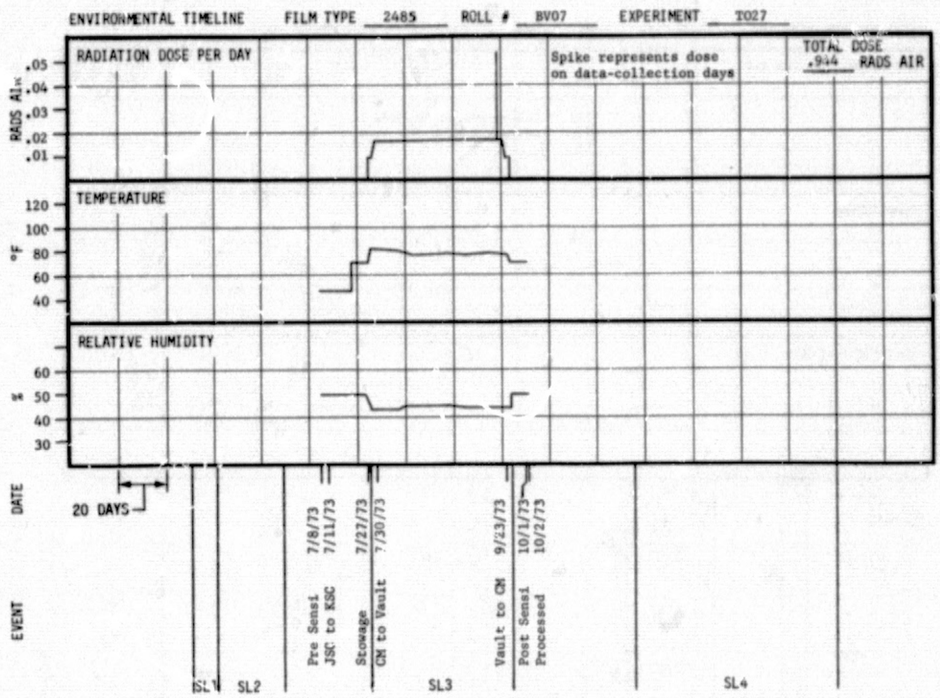


FIGURE D-59, FILM TYPE 2485, ROLL BV02



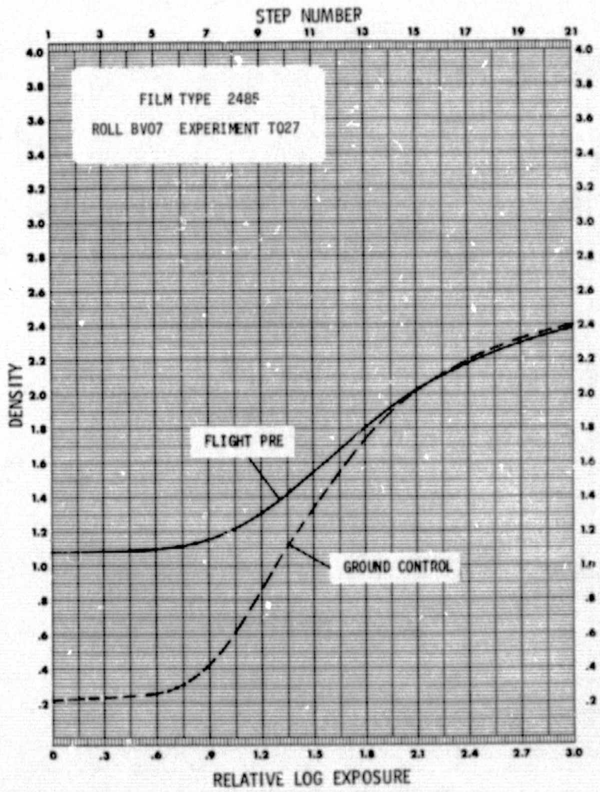
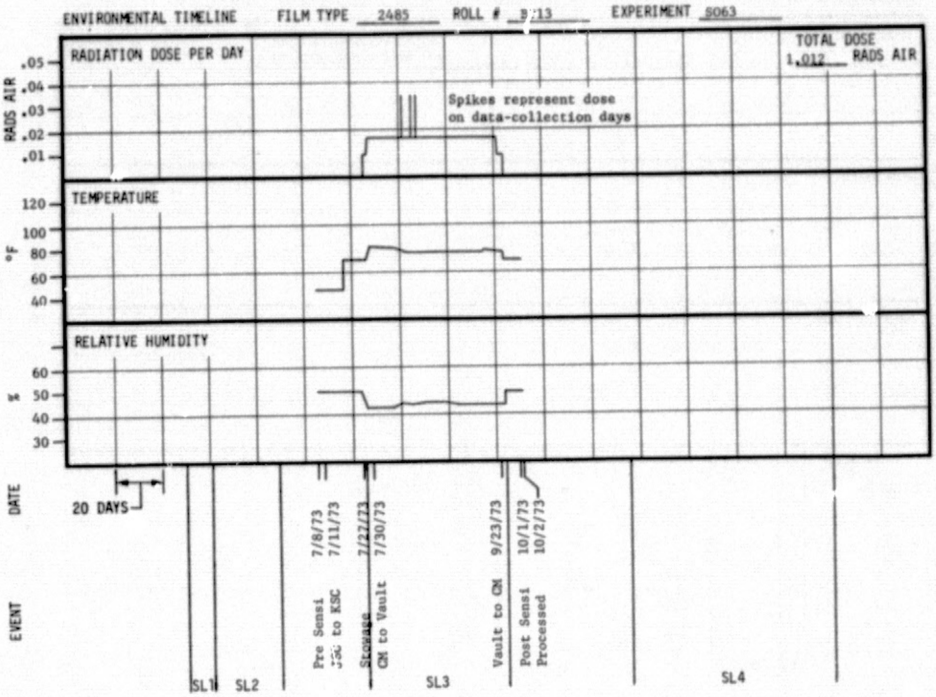


FIGURE D-60, FILM TYPE 2485, ROLL BV07



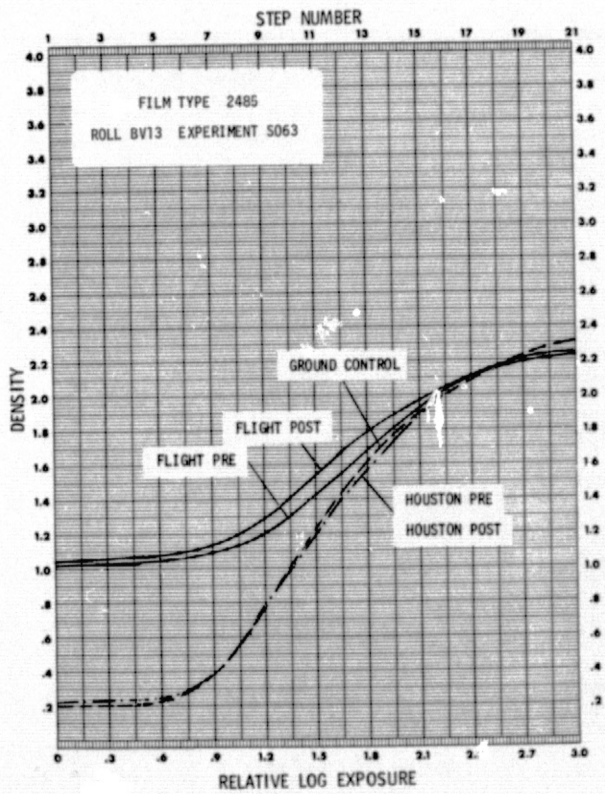
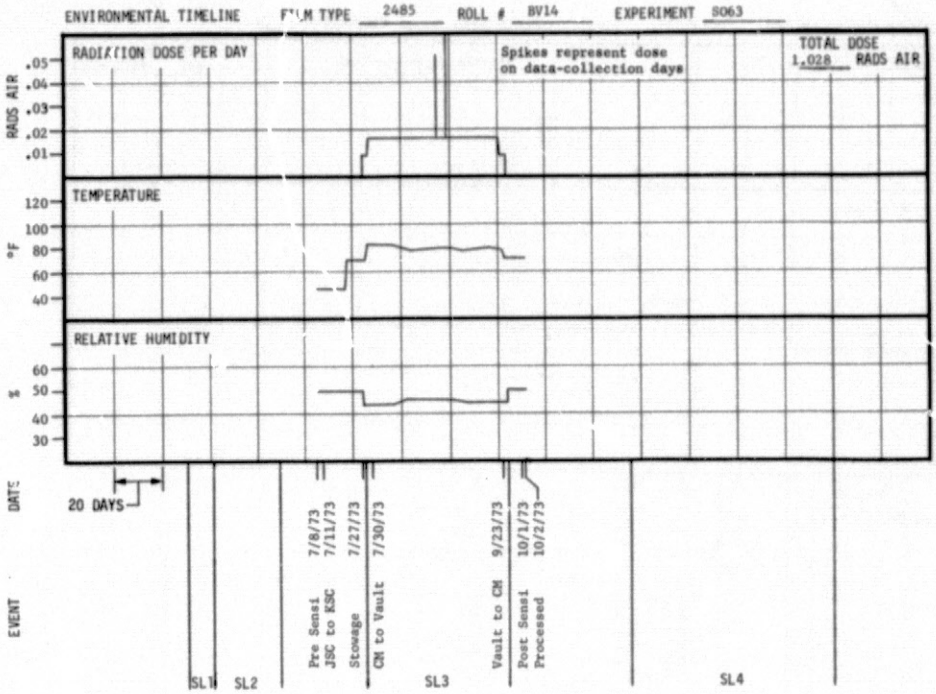


FIGURE D-61, FILM TYPE 2485, ROLL BV13



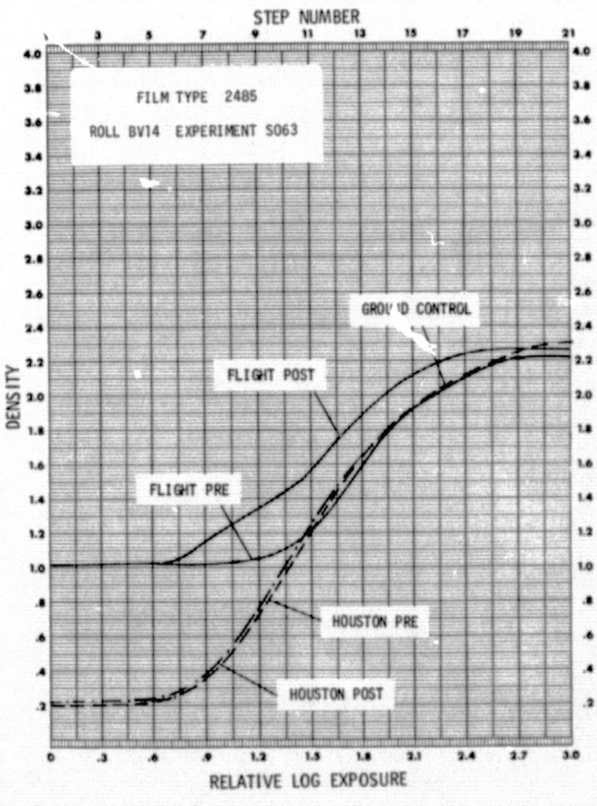
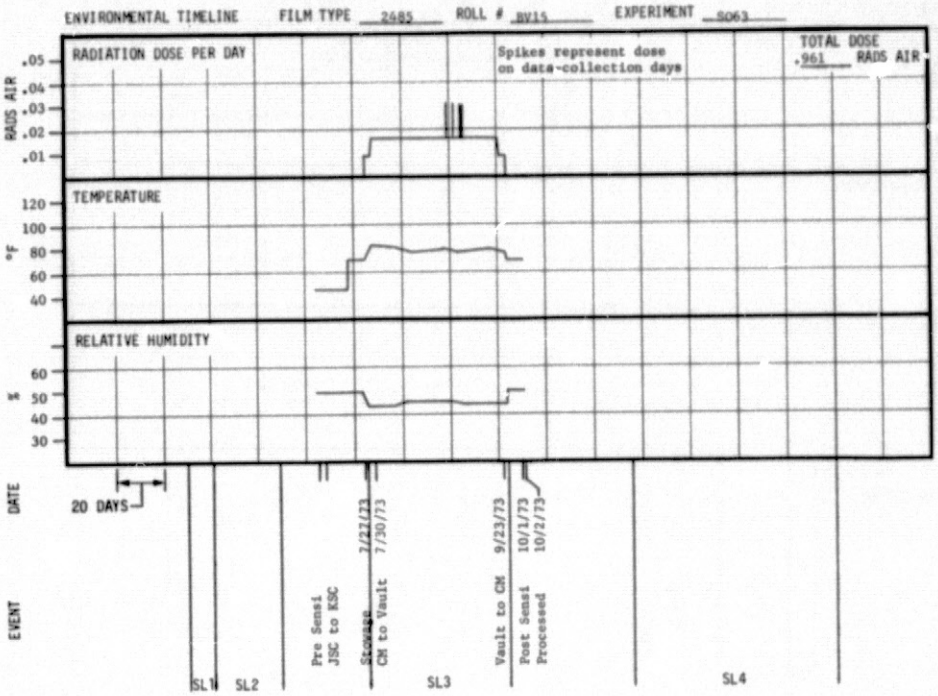


FIGURE D-62, FILM TYPE 2485, ROLL BV14



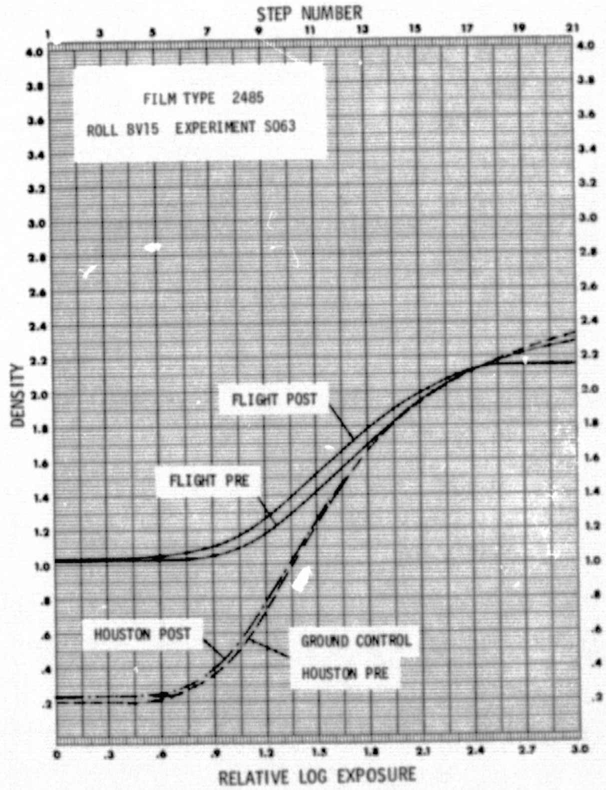
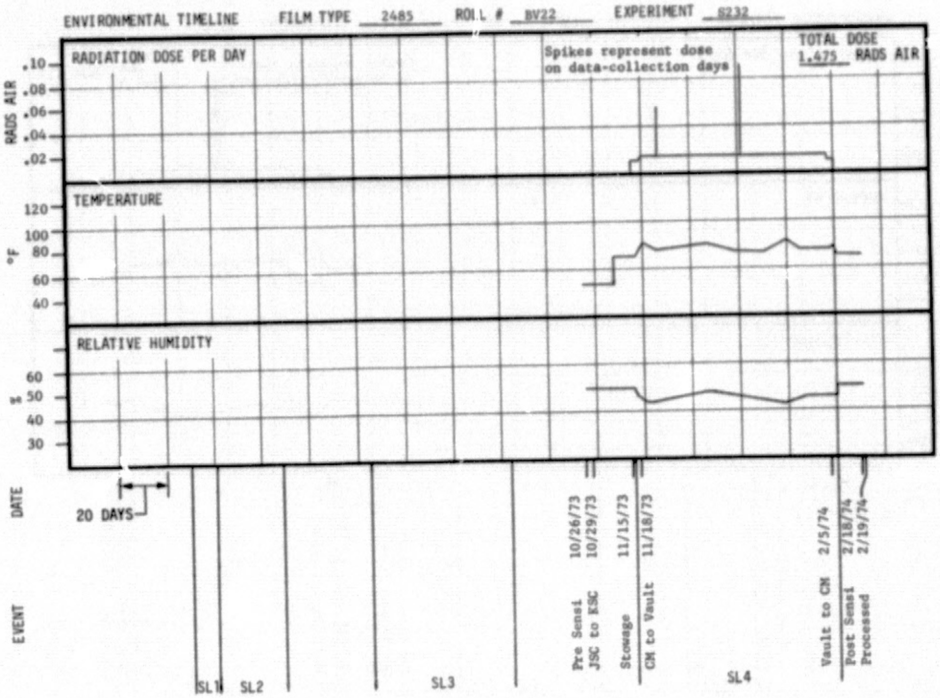


FIGURE D-63, FILM TYPE 2485, ROLL BV15



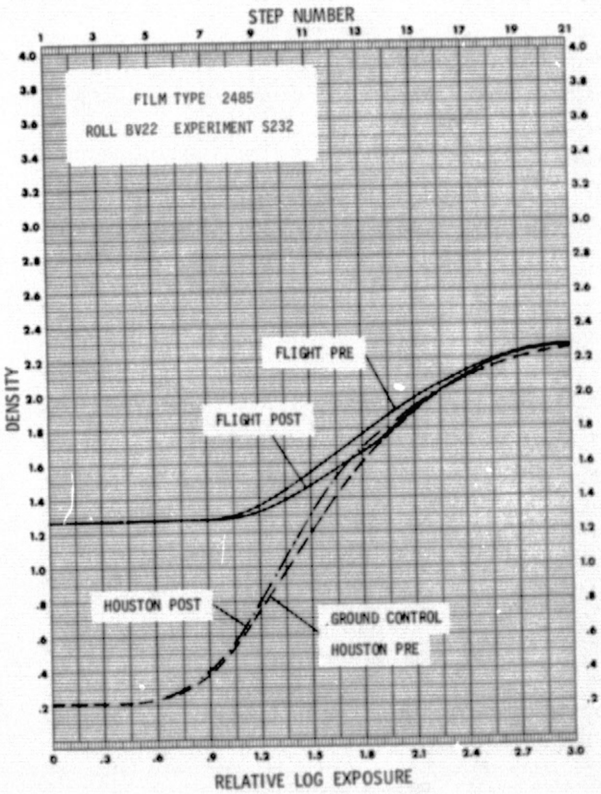
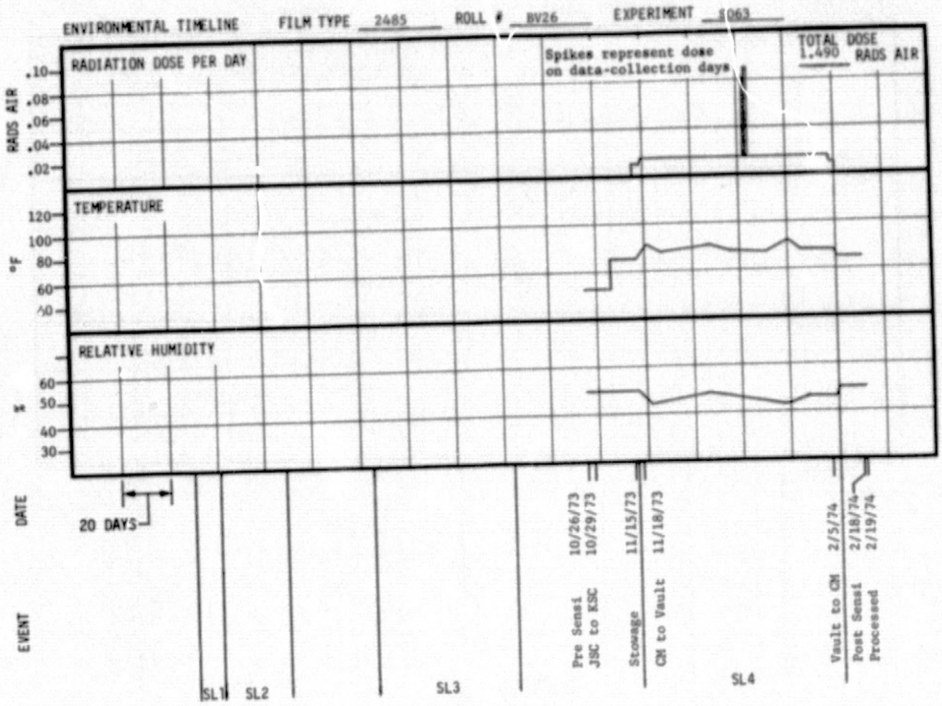


FIGURE D-64, FILM TYPE 2485, ROLL BV22



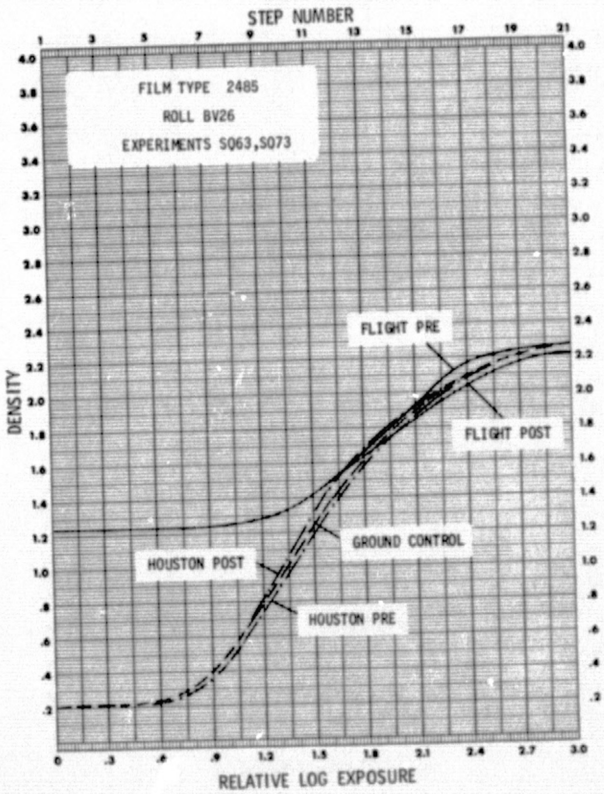
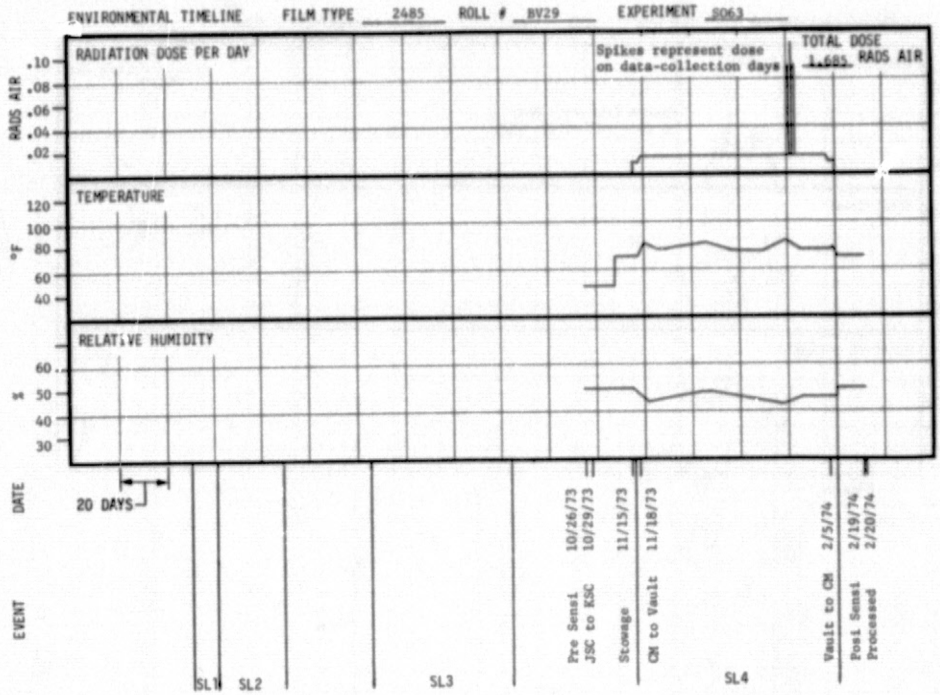


FIGURE D-65, FILM TYPE 2485, ROLL BV26



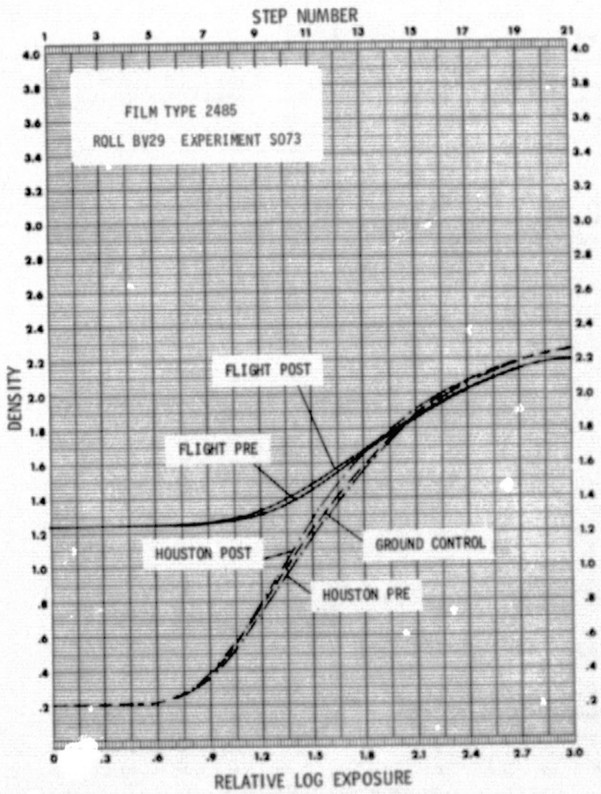
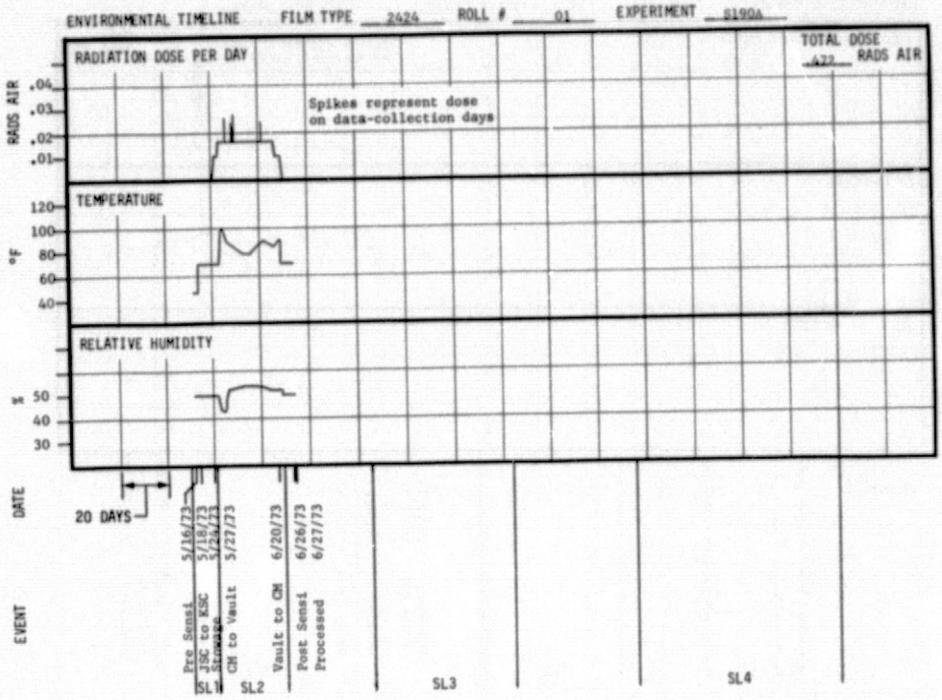


FIGURE D-66, FILM TYPE 2485, ROLL BV29



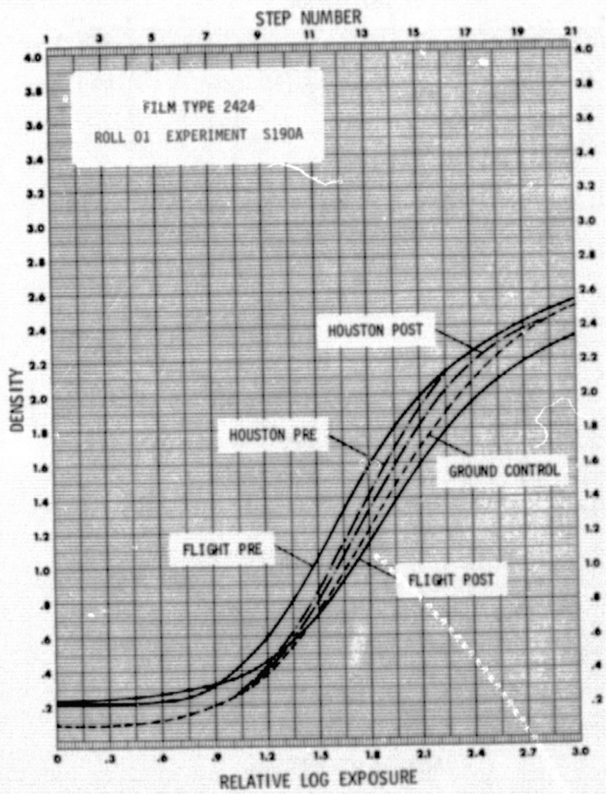
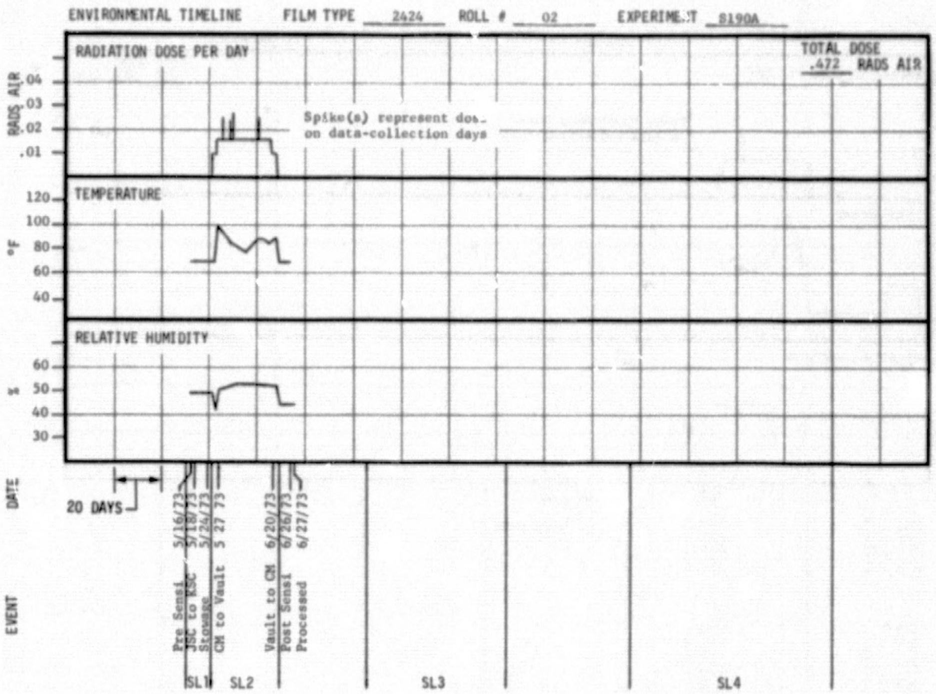


FIGURE D-67, FILM TYPE 2424, ROLL 01



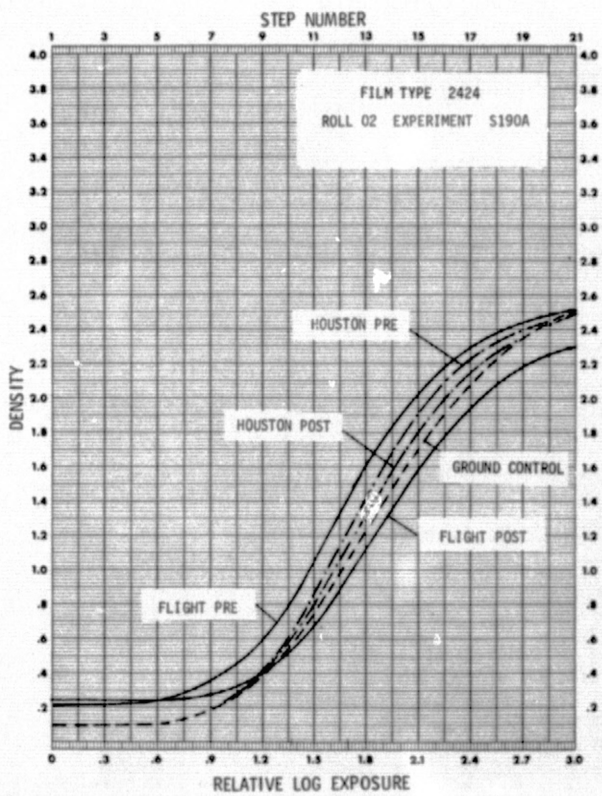
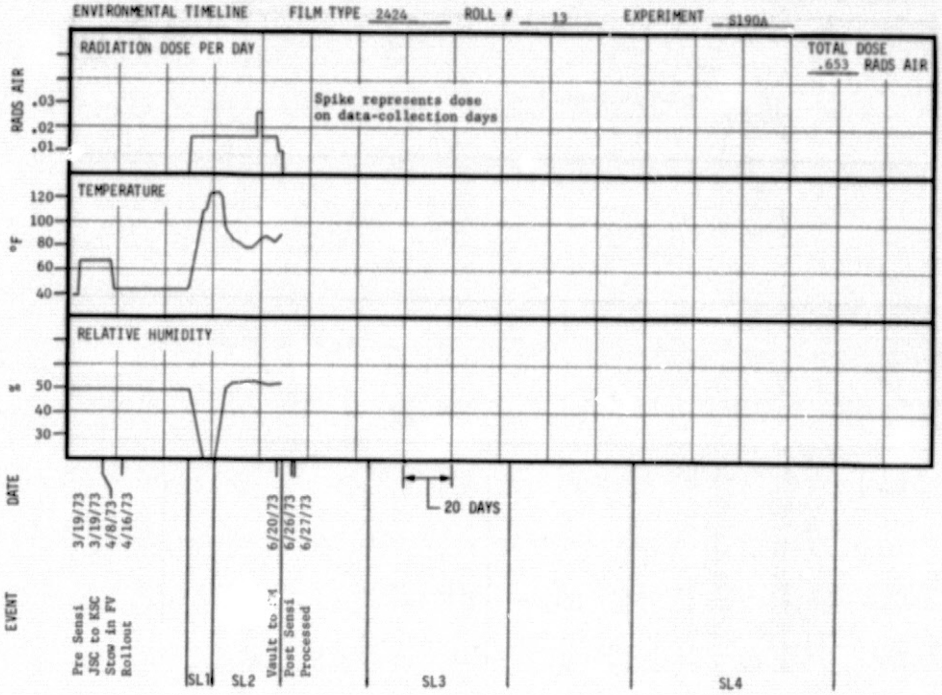


FIGURE D-68, FILM TYPE 2424, ROLL 02



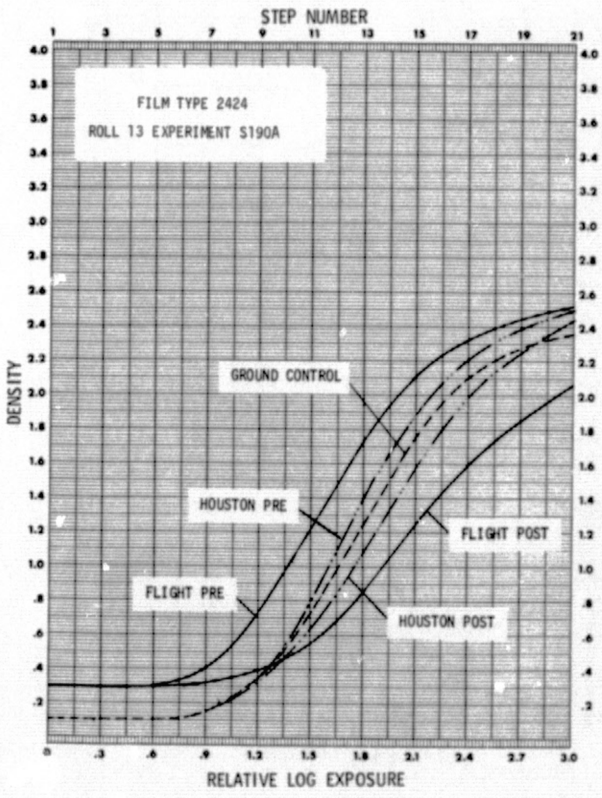
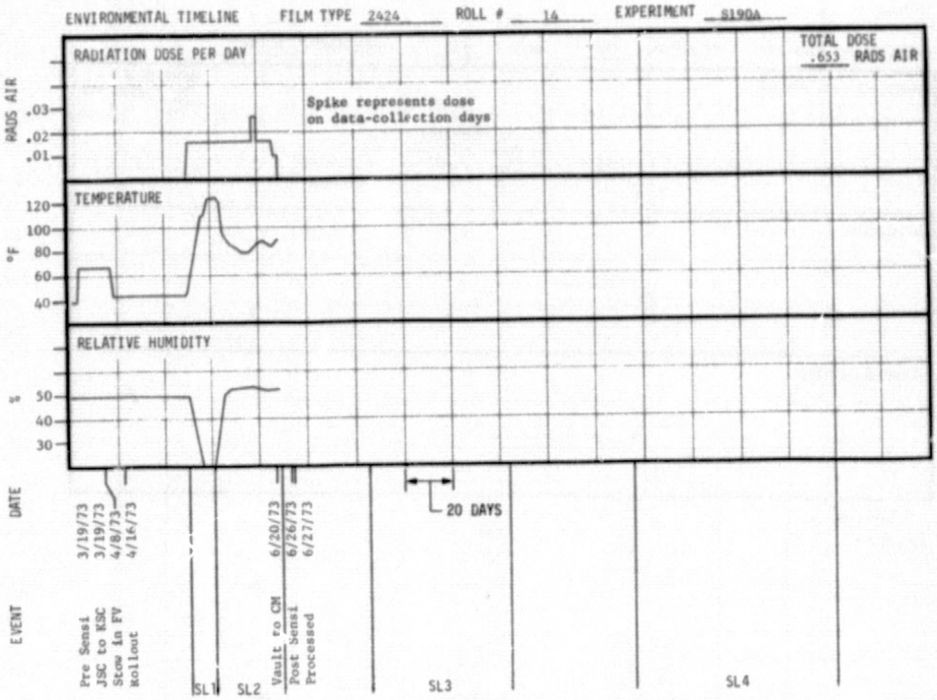


FIGURE D-69. FILM TYPE 2424, ROLL 13



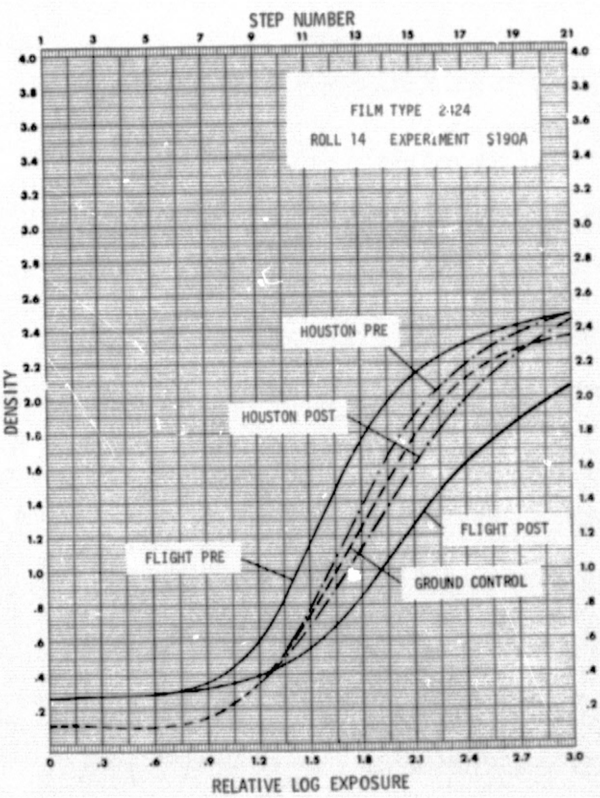
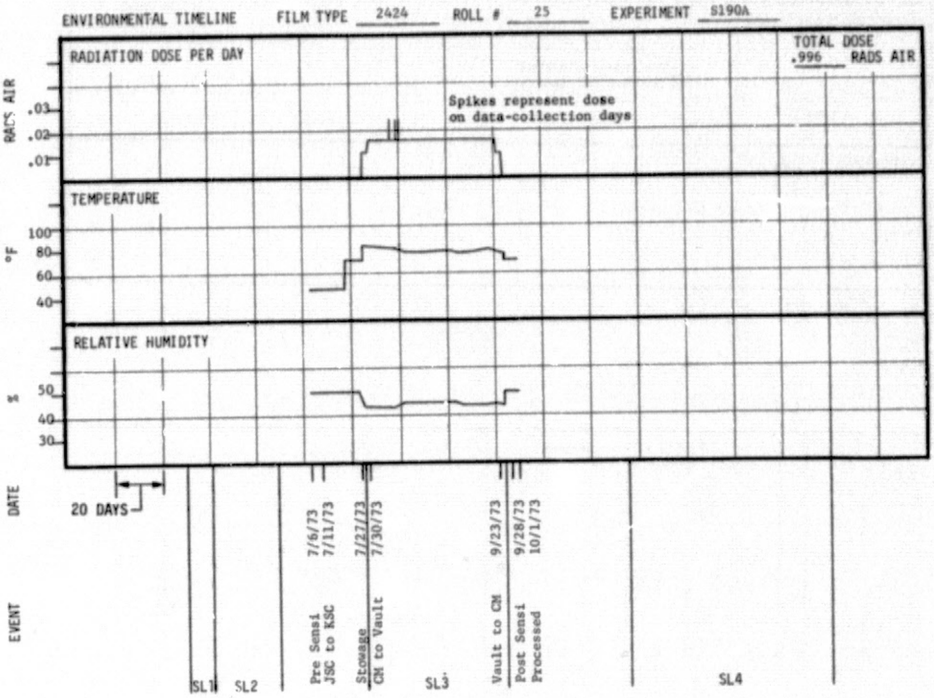


FIGURE D-70, FILM TYPE 2424, ROLL 14



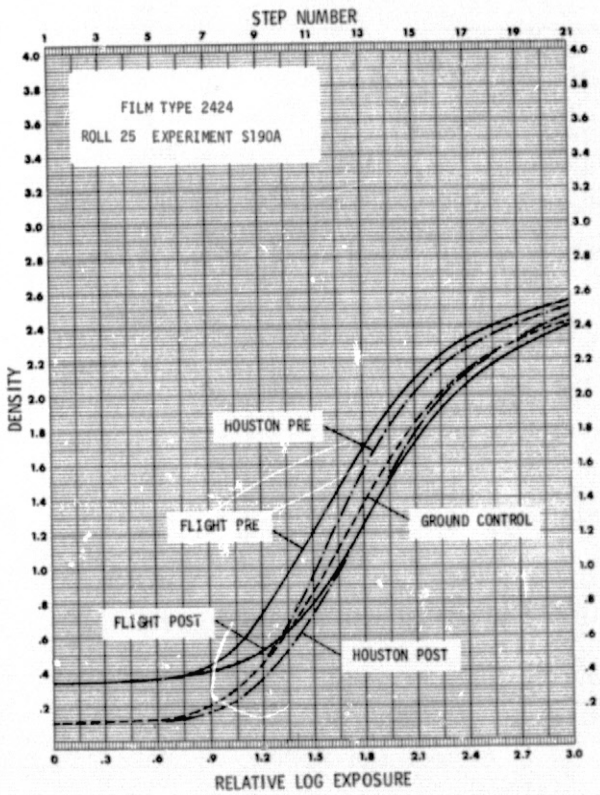
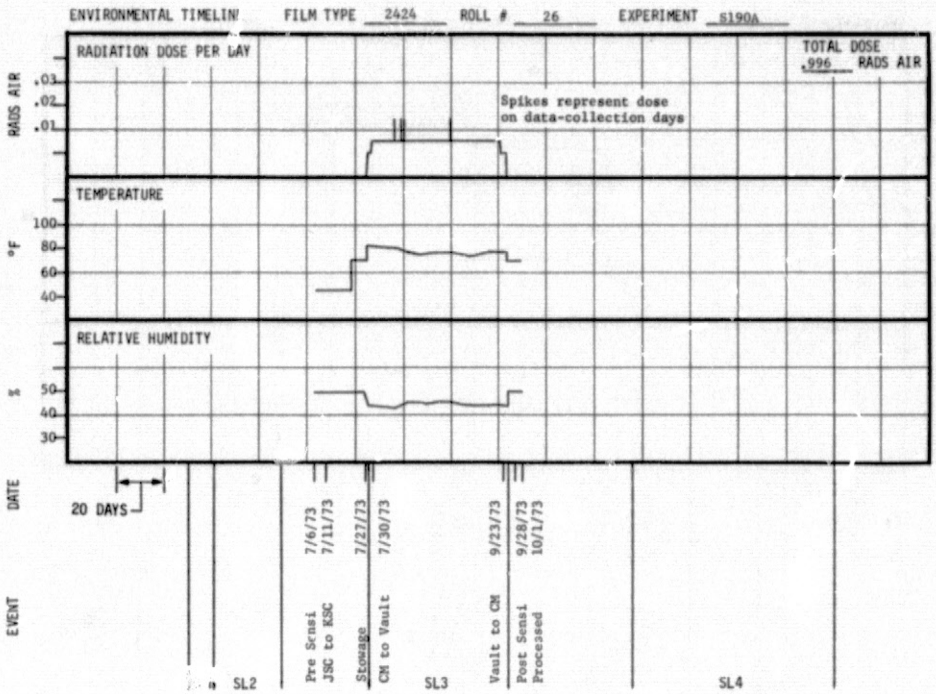


FIGURE D-71, FILM TYPE 2424, ROLL 25



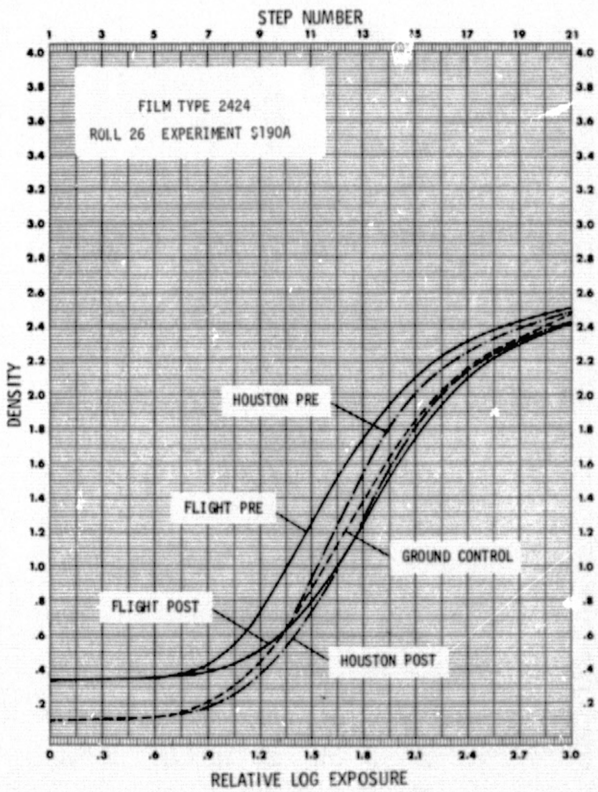
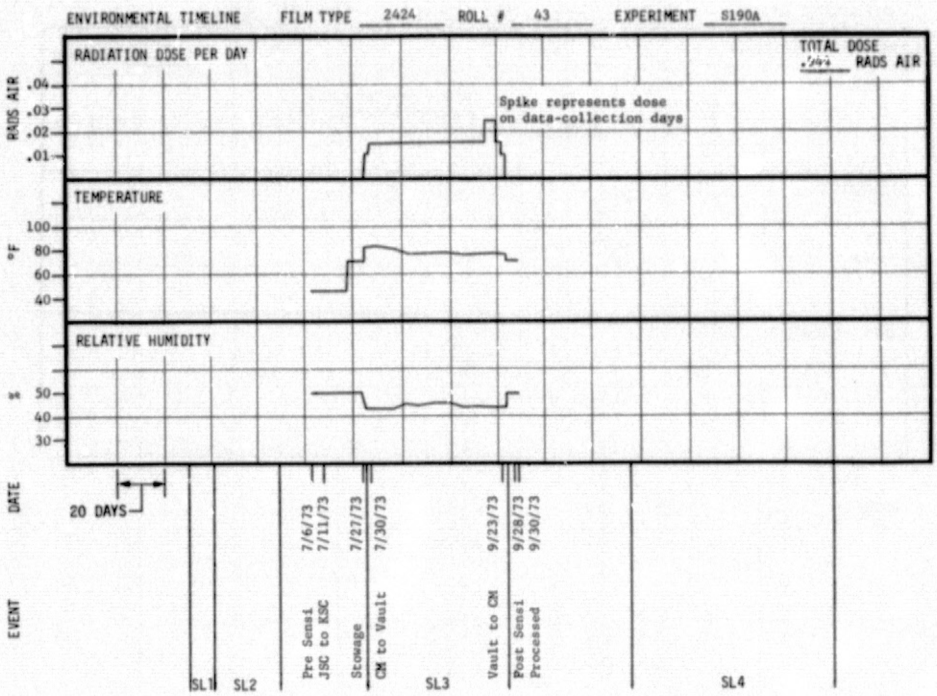


FIGURE D-72, FILM TYPE 2424, ROLL 26



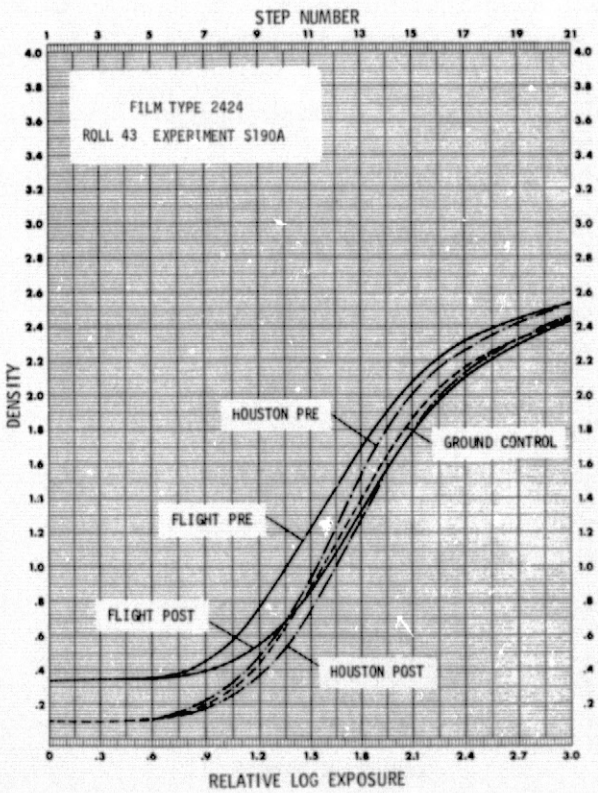
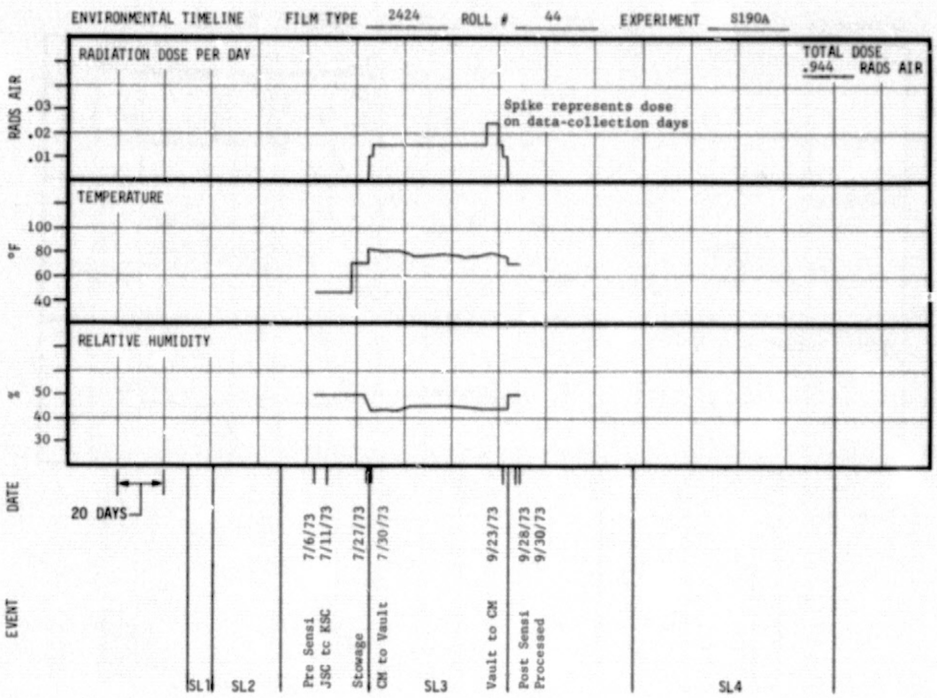


FIGURE D-73, FILM TYPE 2424, ROLL 43



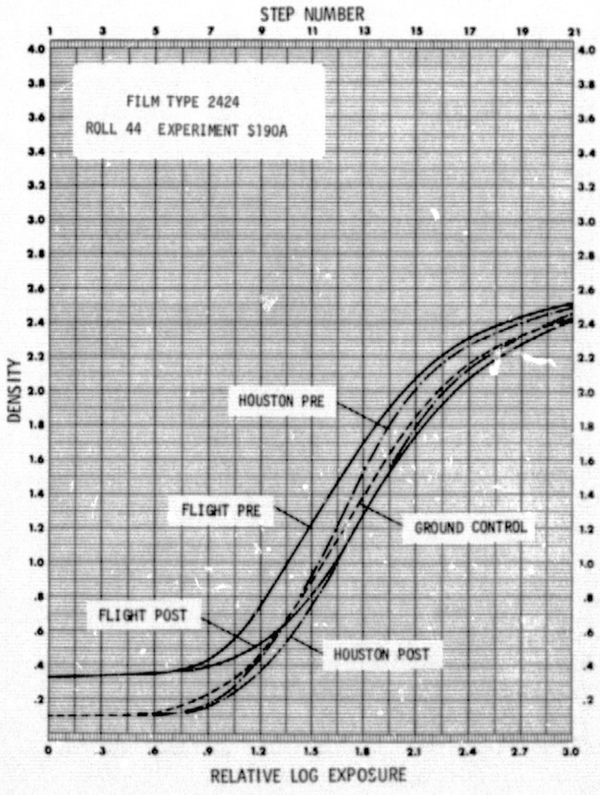
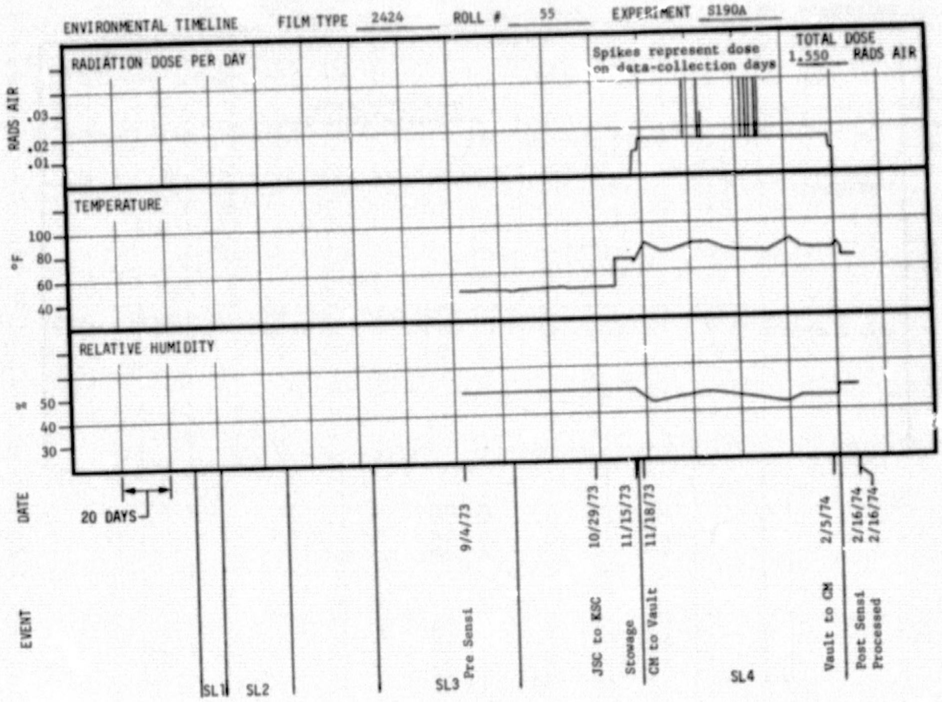


FIGURE D-74, FILM TYPE 2424, ROLL 44



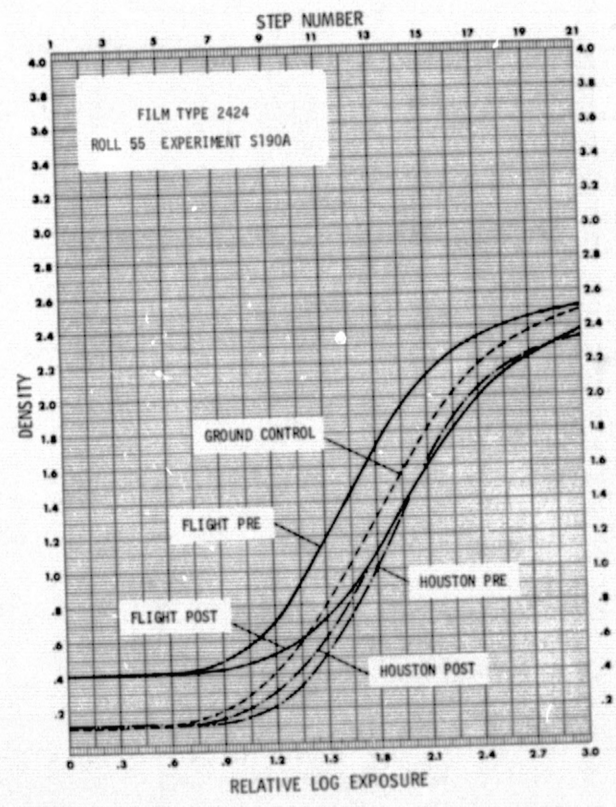
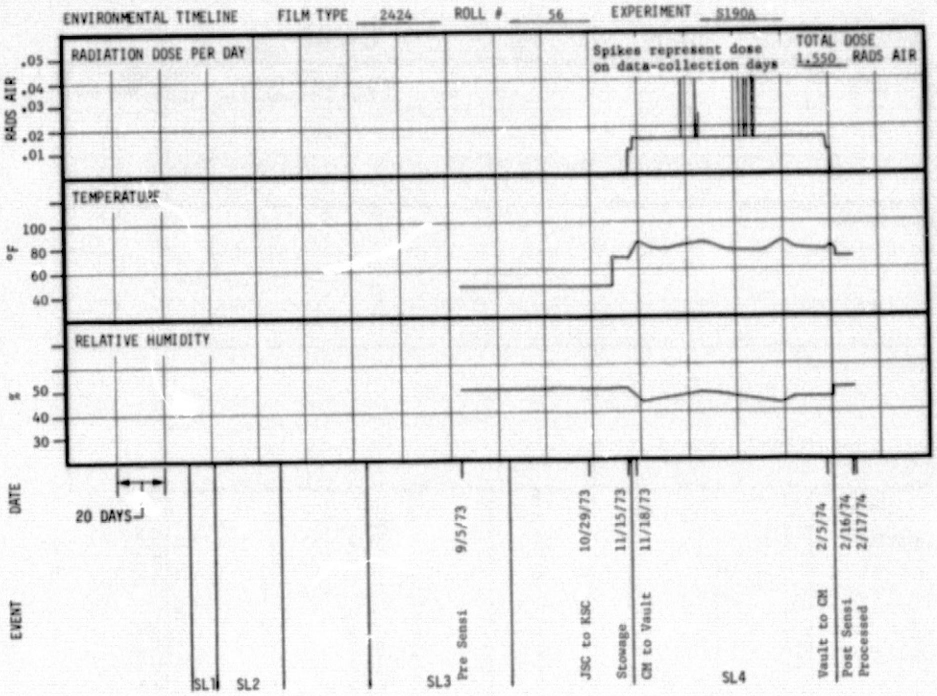


FIGURE D-75, FILM TYPE 2424, ROLL 55



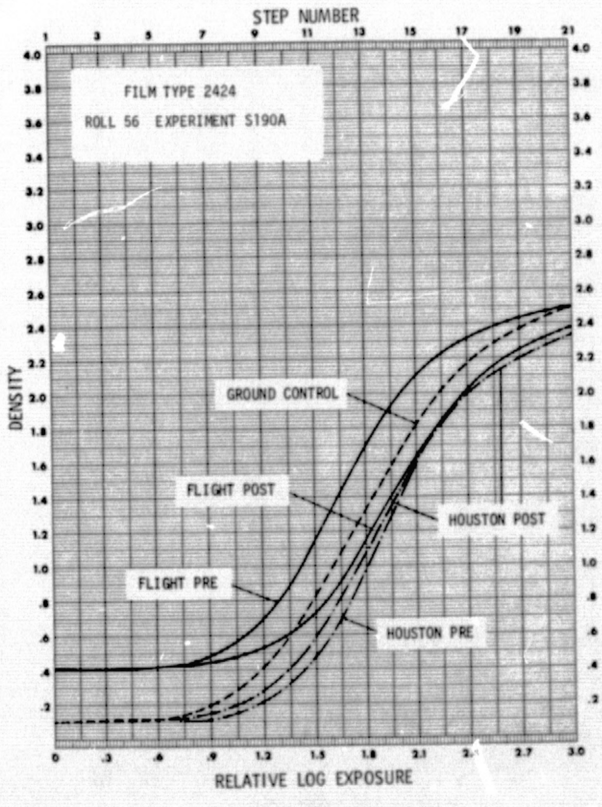
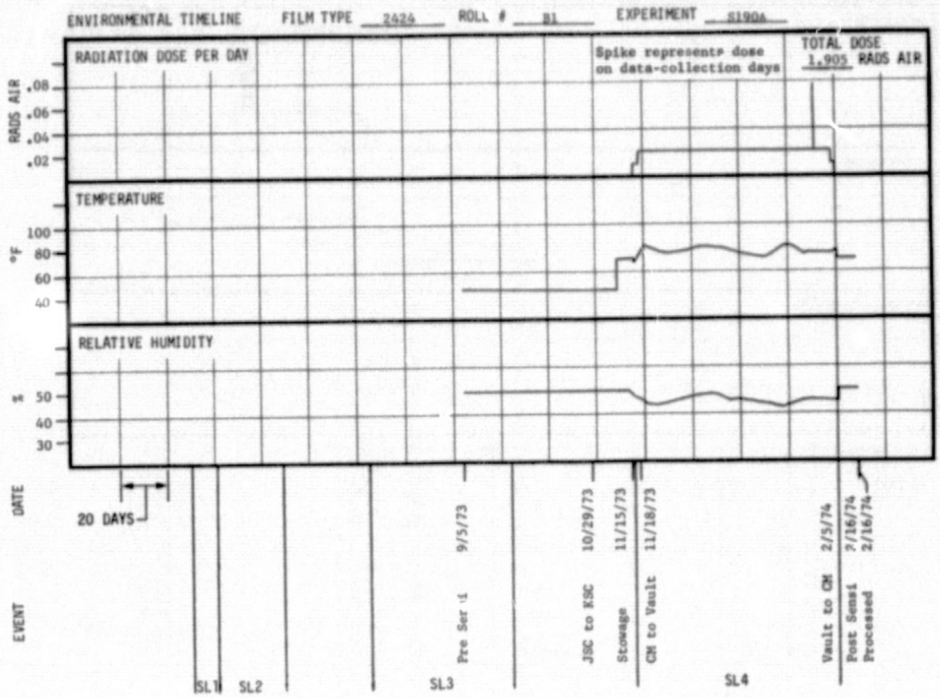


FIGURE D-76. FILM TYPE 2424. ROLL 56



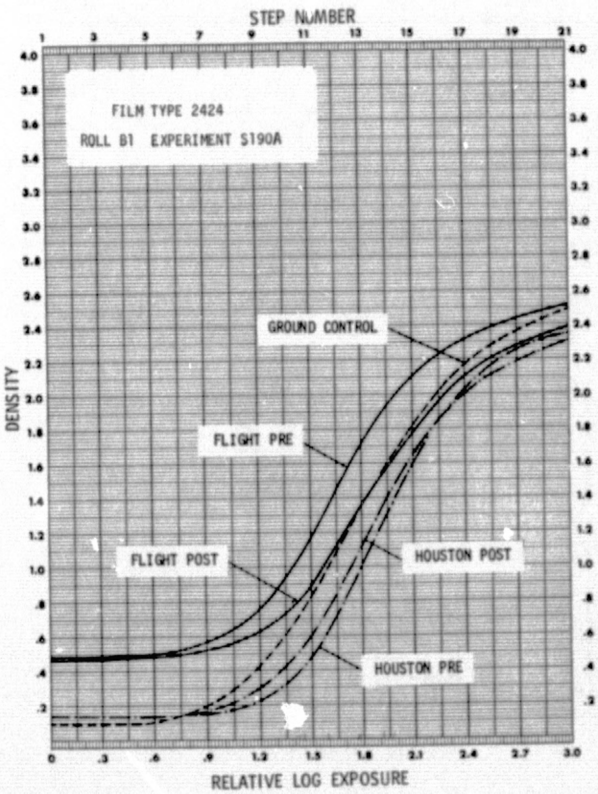
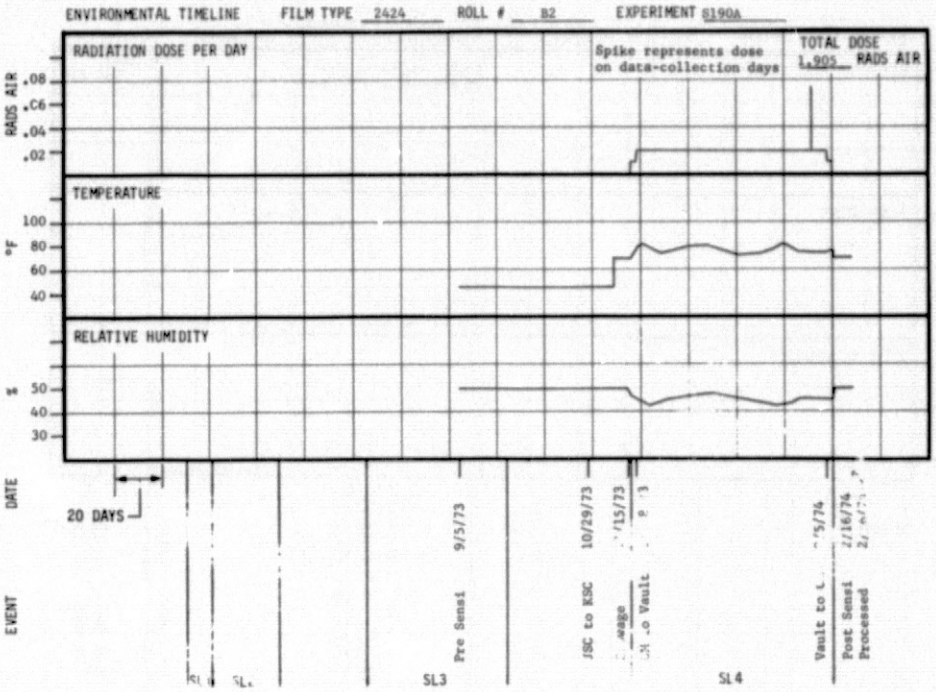


FIGURE D-77, FILM TYPE 2424, ROLL B1



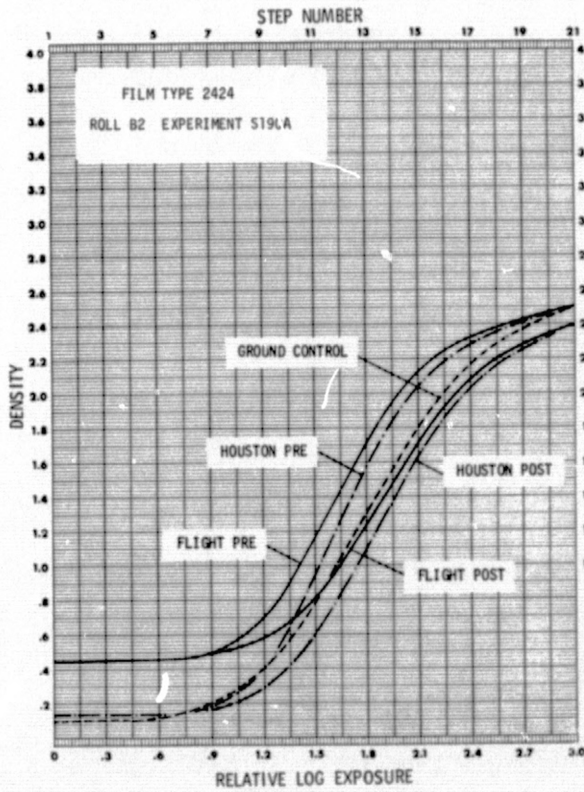
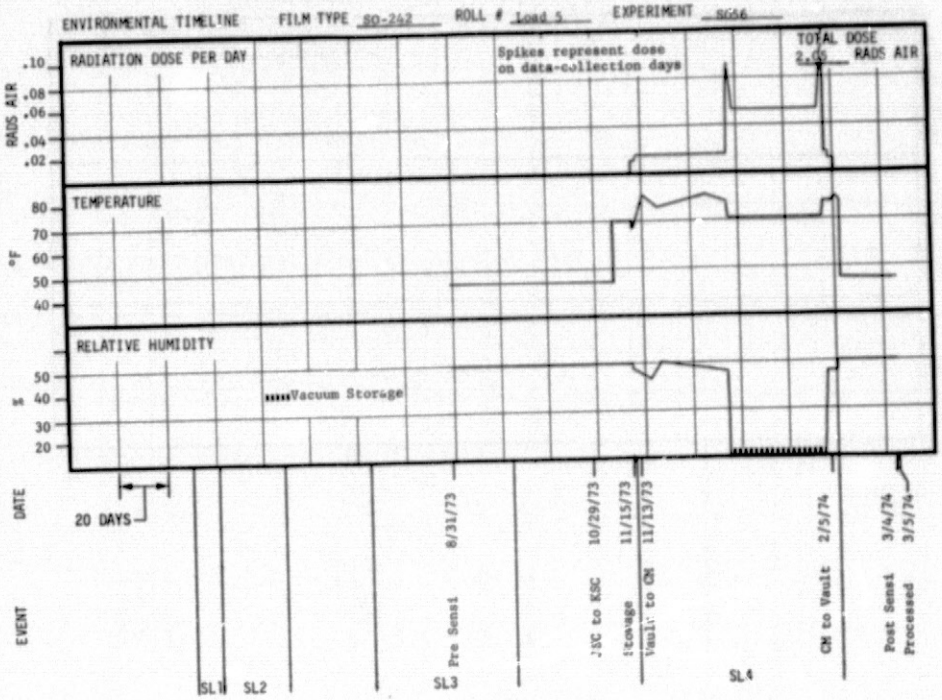


FIGURE D-78, FILM TYPE 2424, ROLL B2



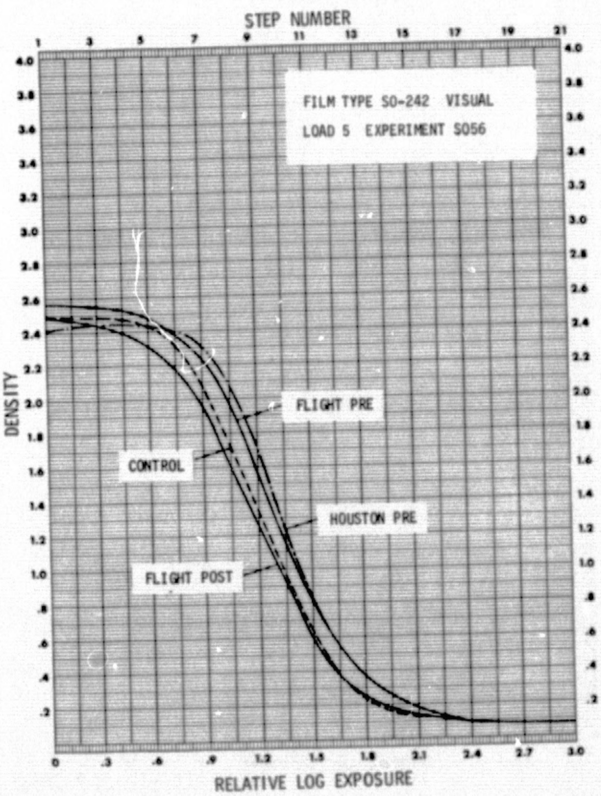
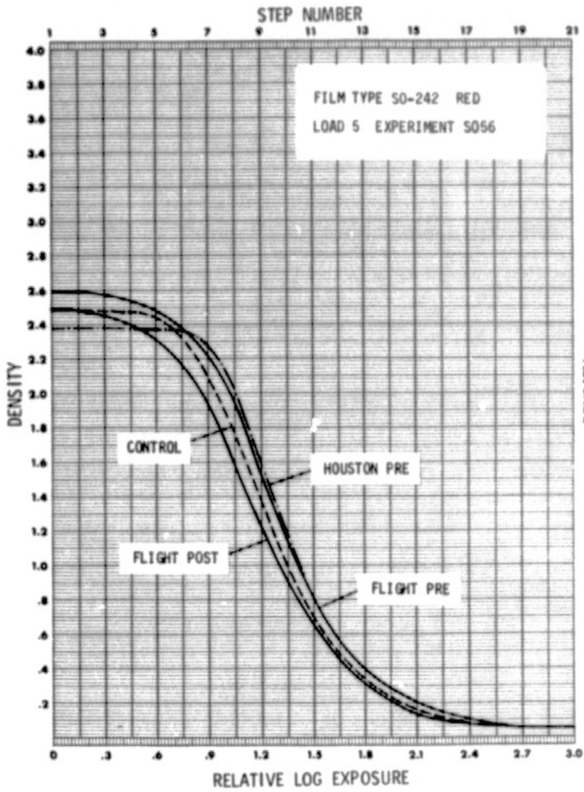
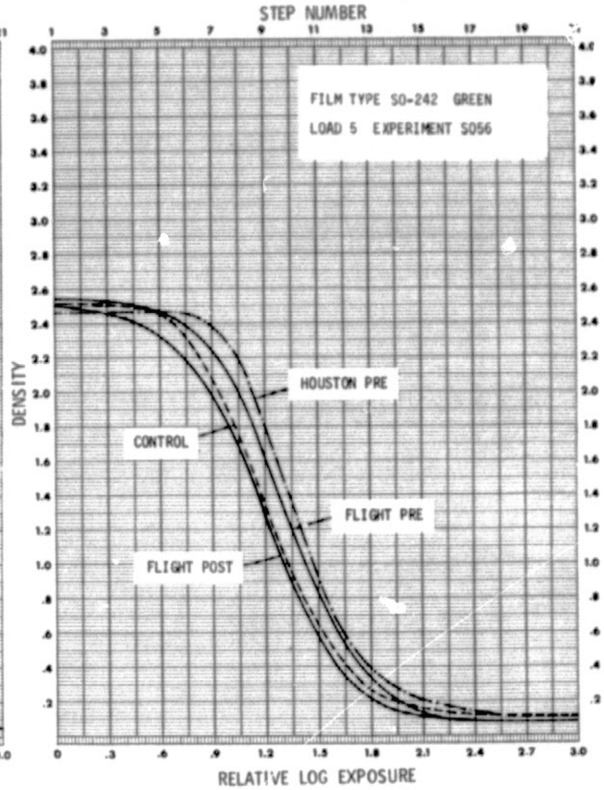


FIGURE D-79, FILM TYPE SO-242, LOAD 5 (S056)





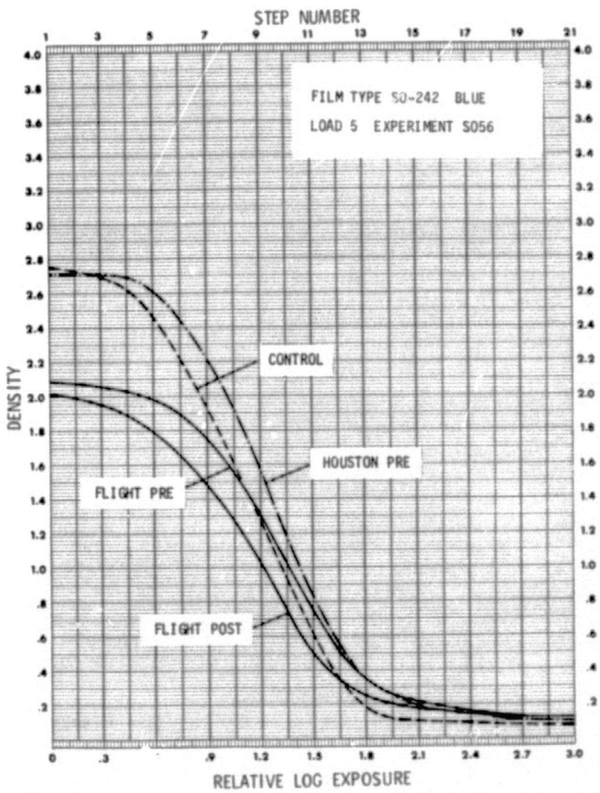
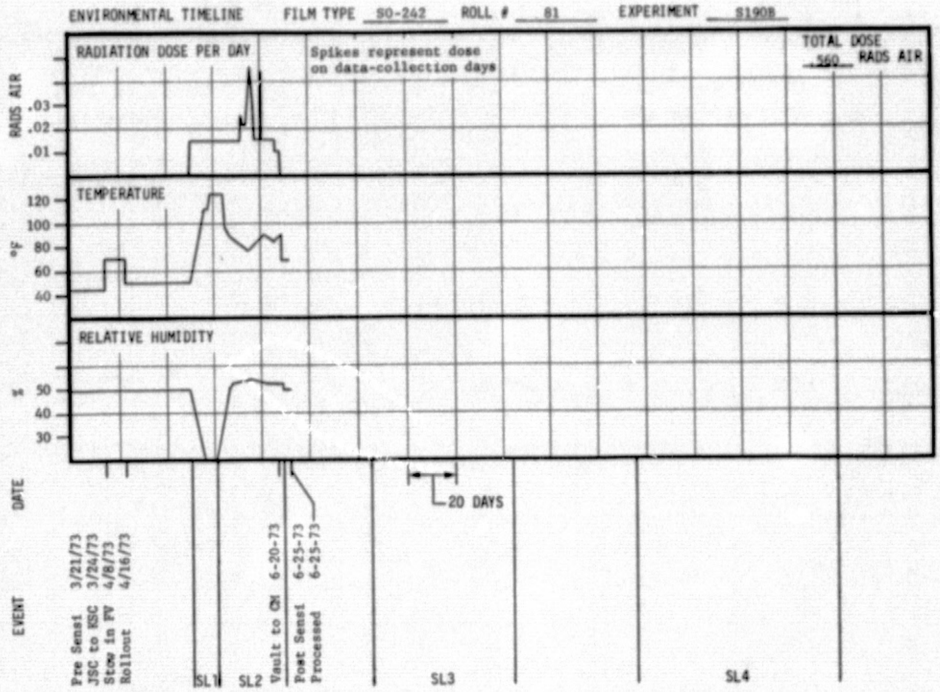


FIGURE D-79, FILM TYPE SO-242, LOAD 5 (S056) (cont)



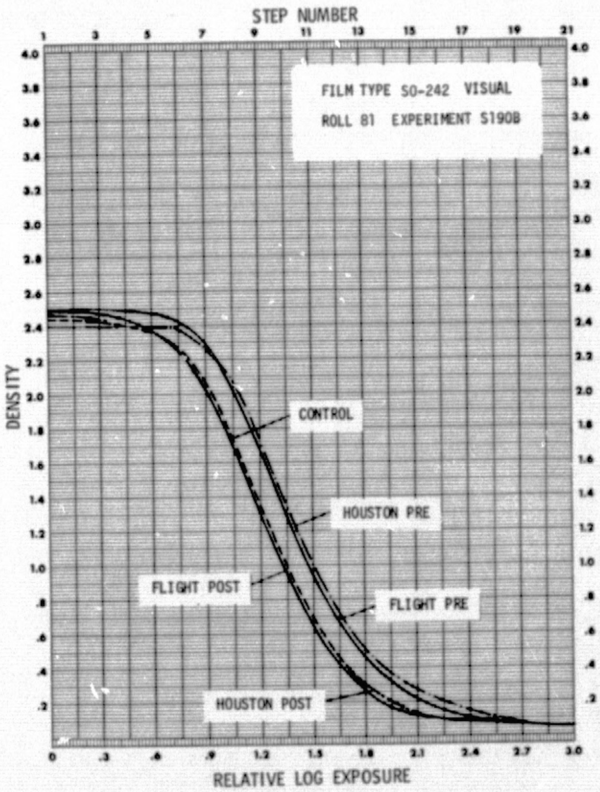
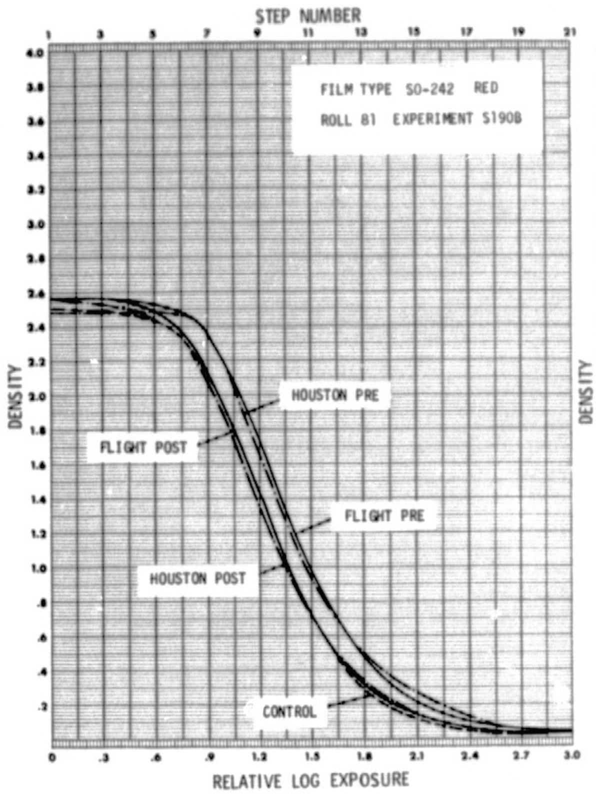
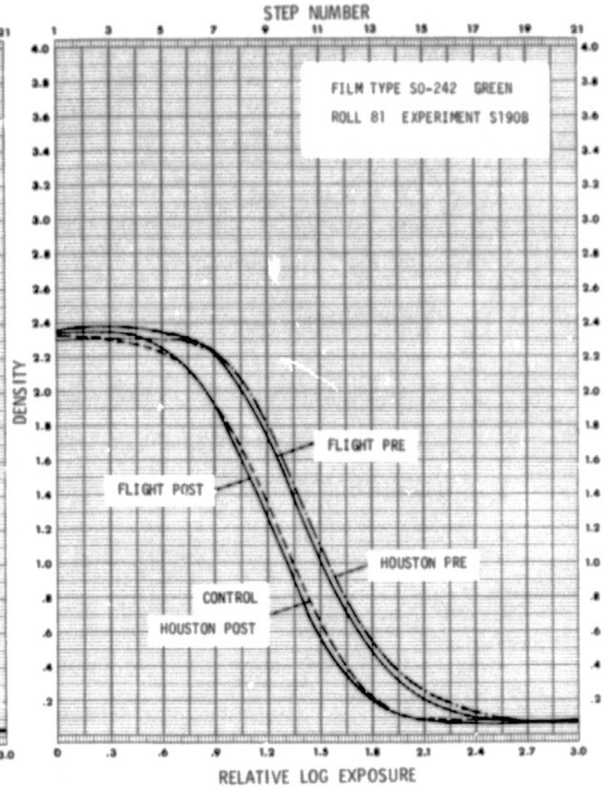


FIGURE D-80, FILM TYPE SO-242, ROLL 81





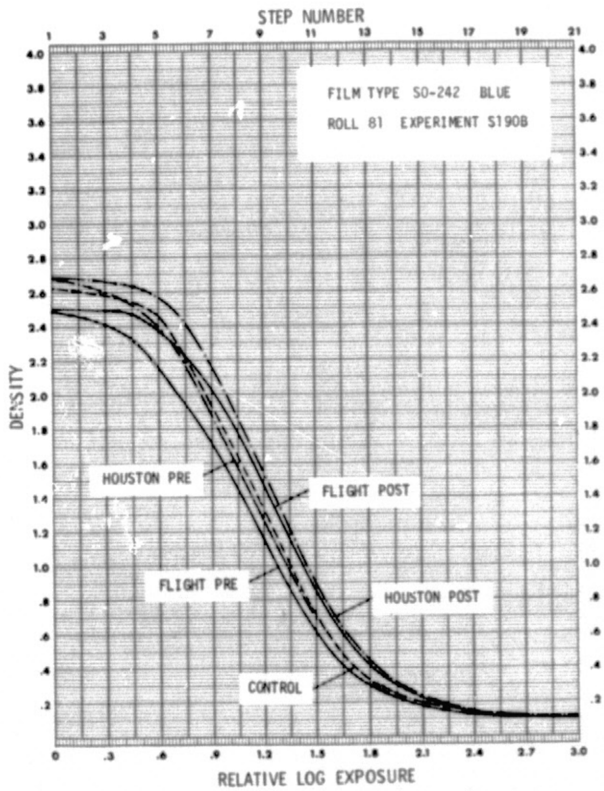
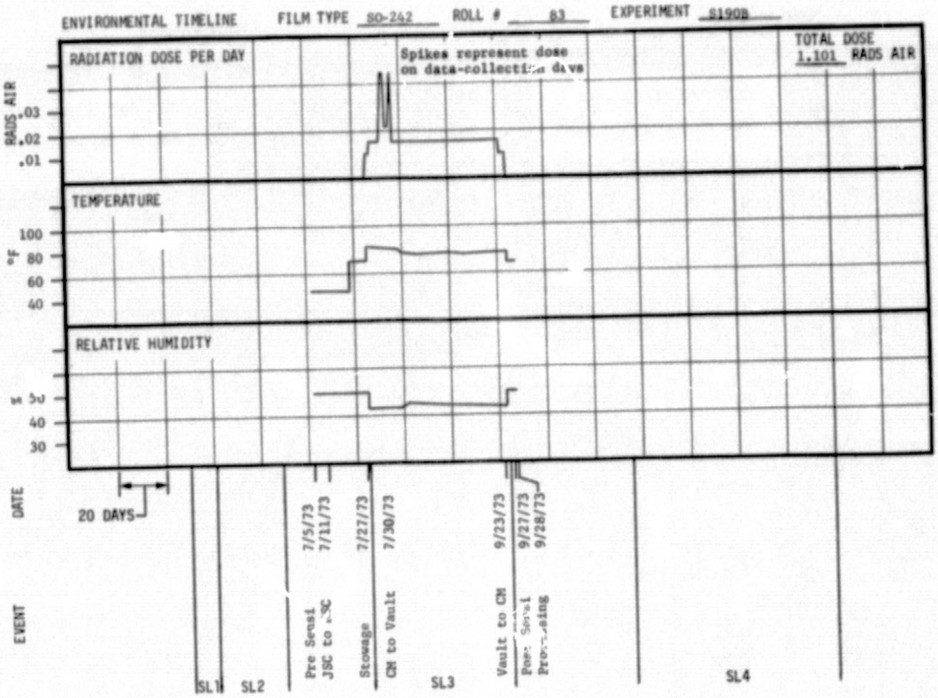


FIGURE D-80, FILM TYPE SO-242, ROLL 81 (cont)



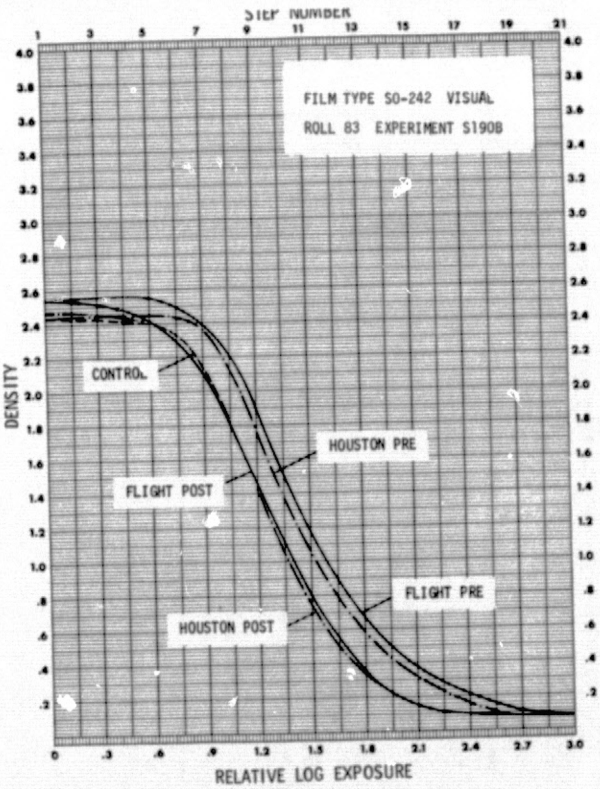
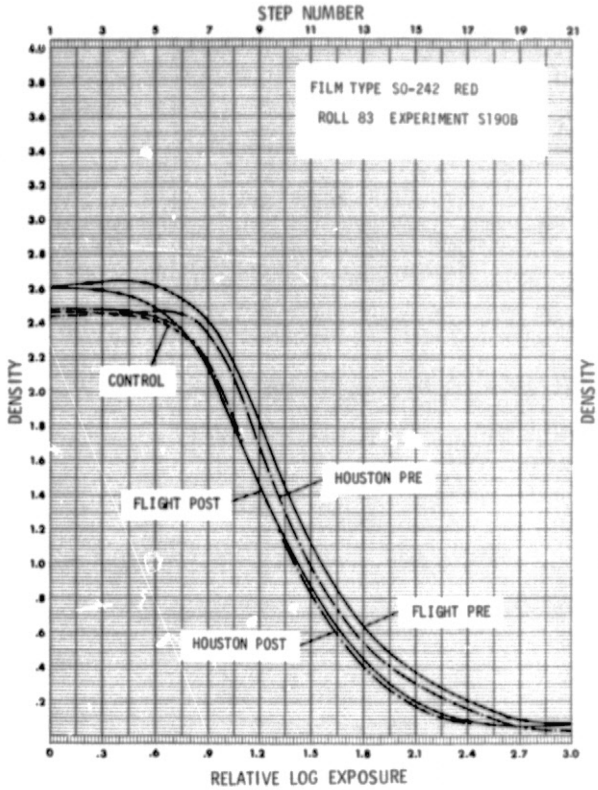
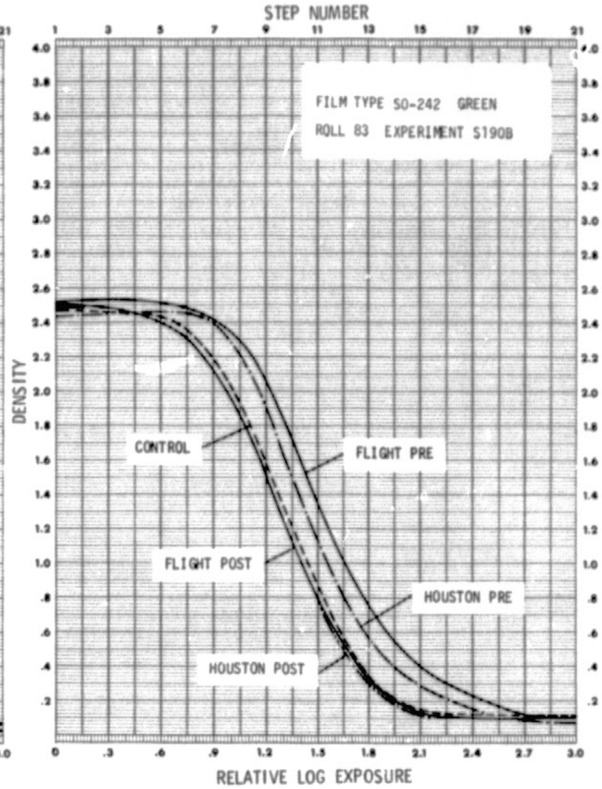


FIGURE D-81, FILM TYPE SO-242, ROLL 83





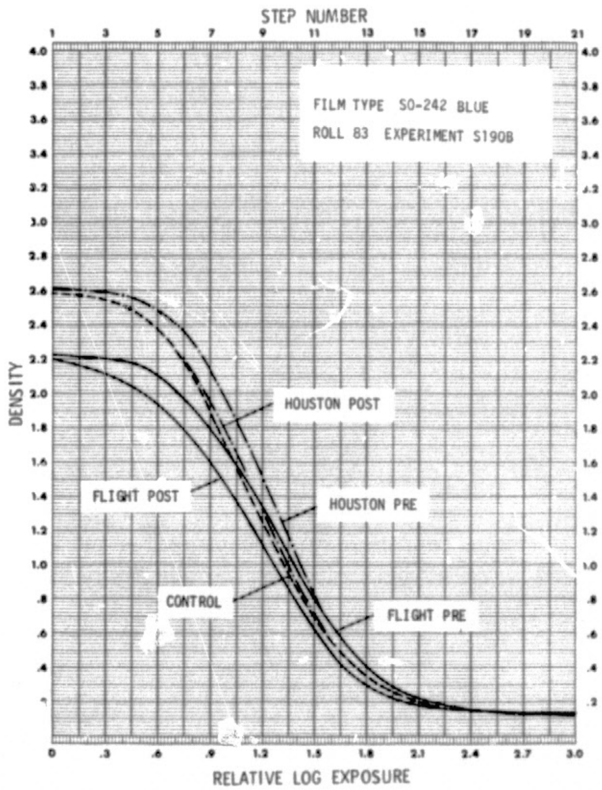
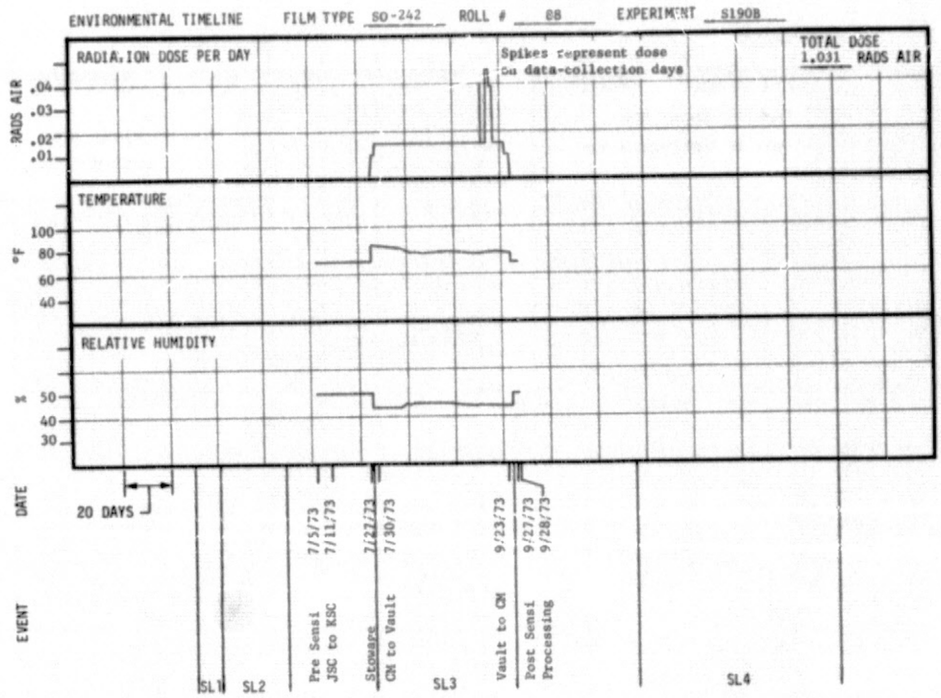


FIGURE D-81, FILM TYPE SO-242, ROLL 83 (cont)



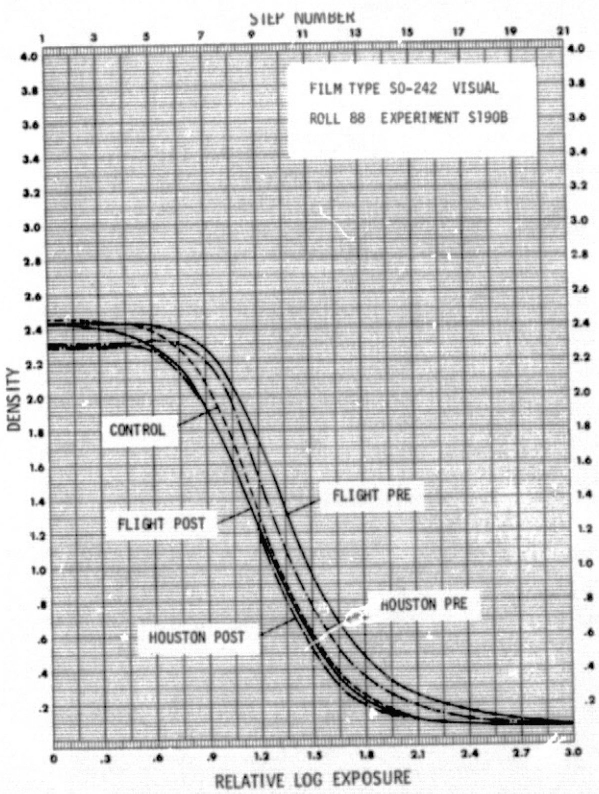


FIGURE D-82, FILM TYPE SO-242, ROLL 88

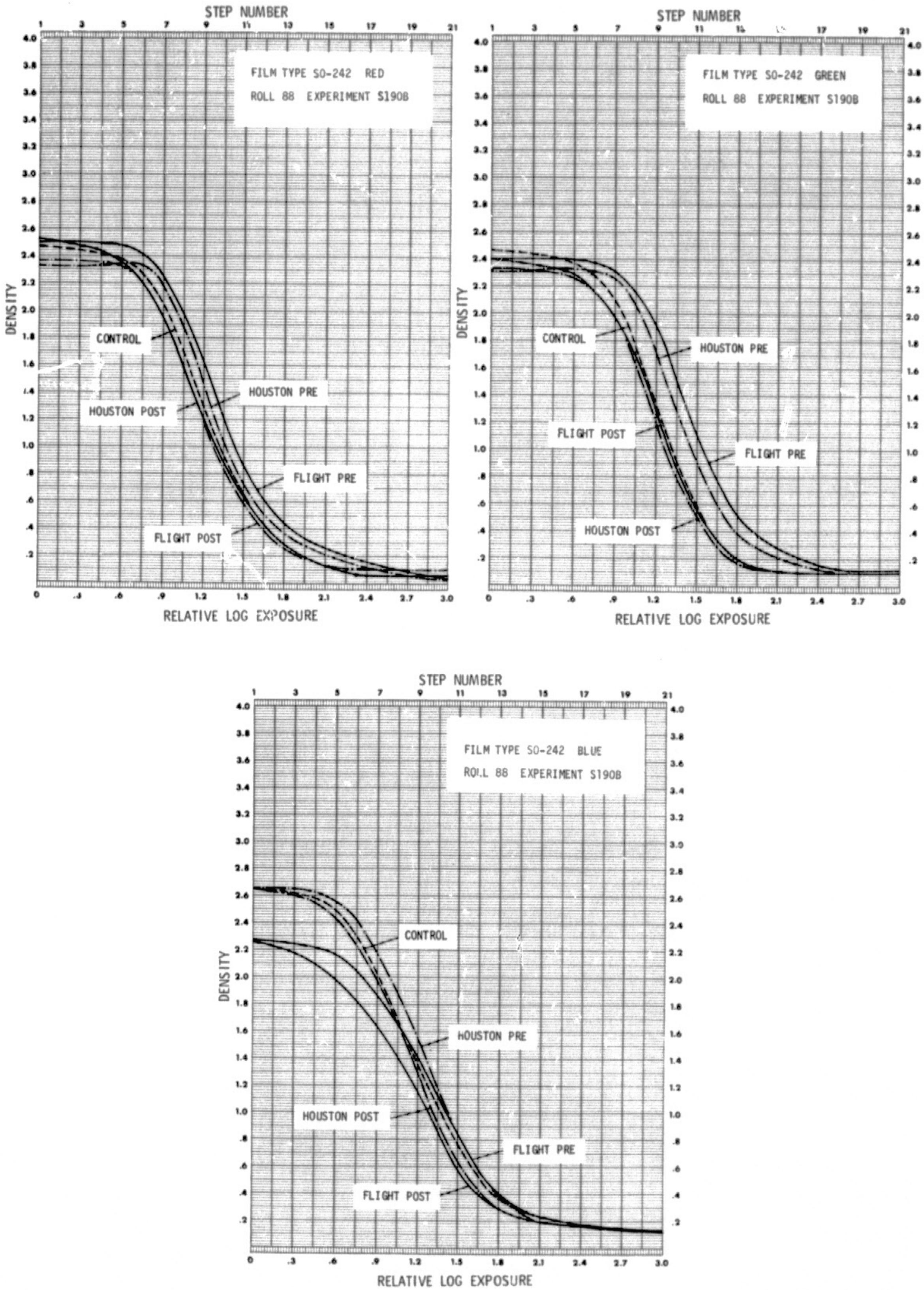
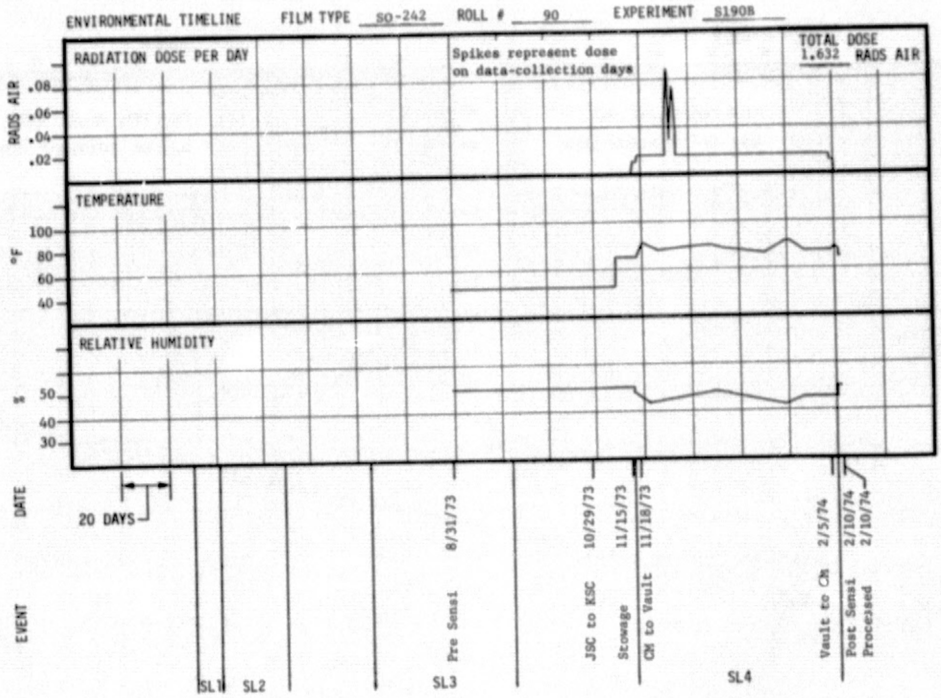


FIGURE D-82, FILM TYPE SO-242, ROLL 88 (cont)



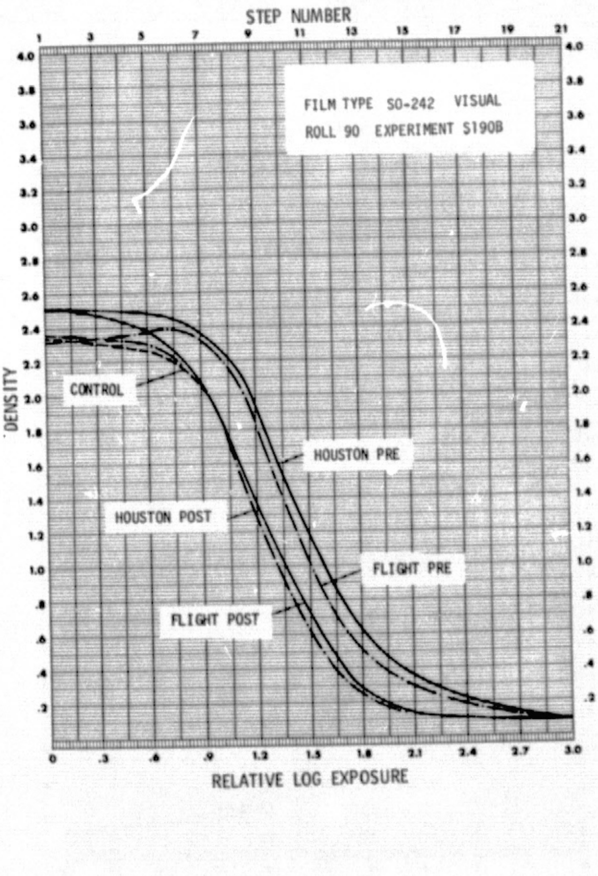
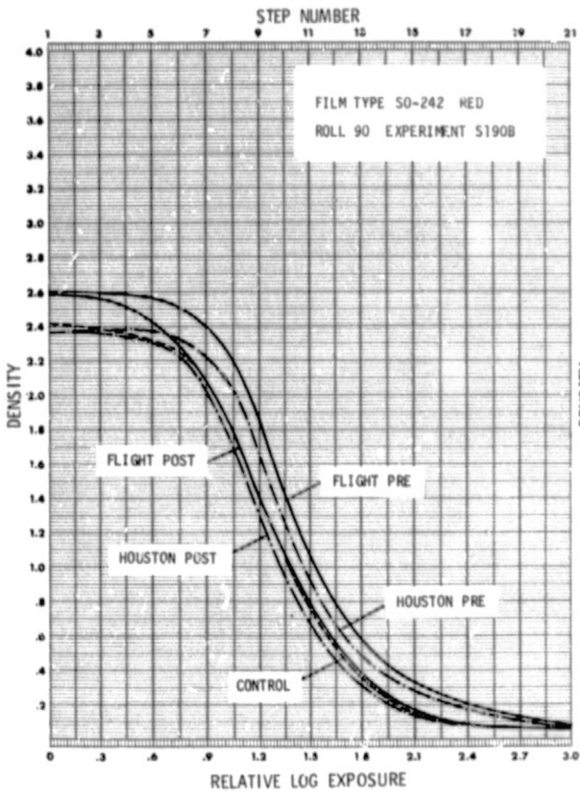
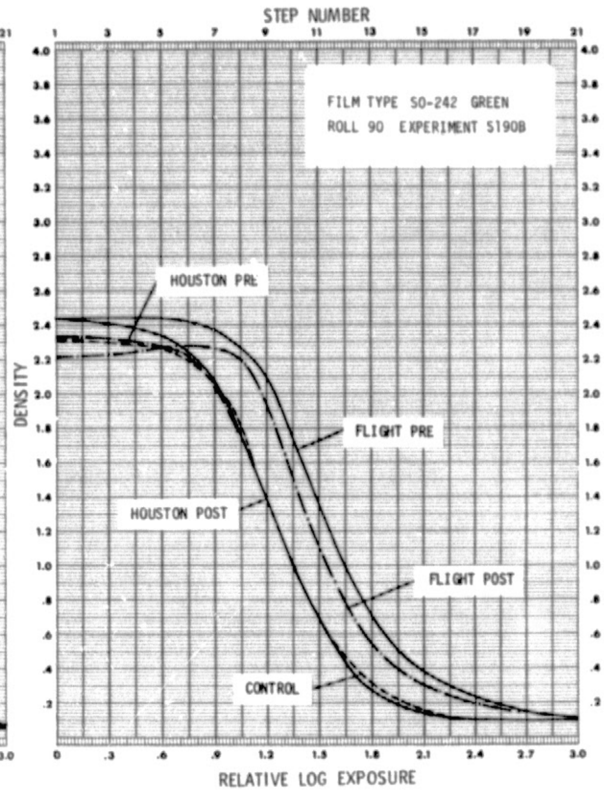


FIGURE D-83, FILM TYPE SO-242, ROLL 90





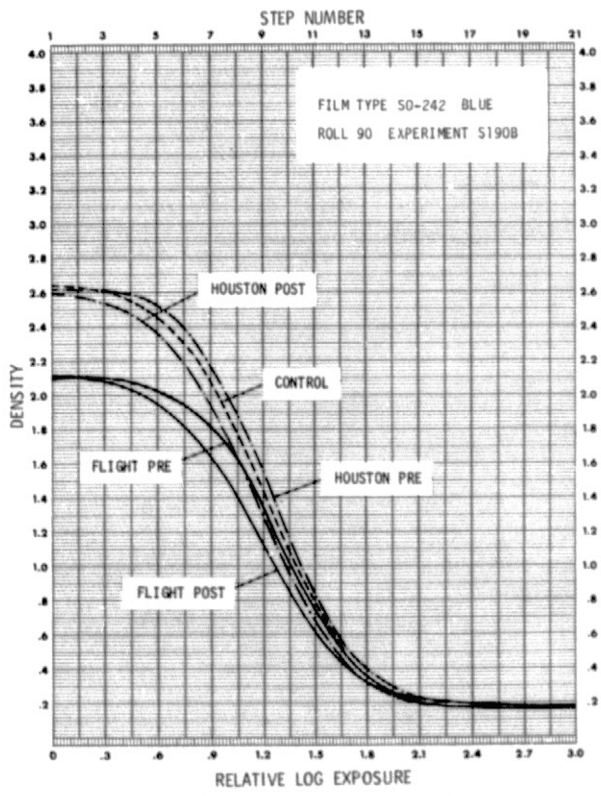
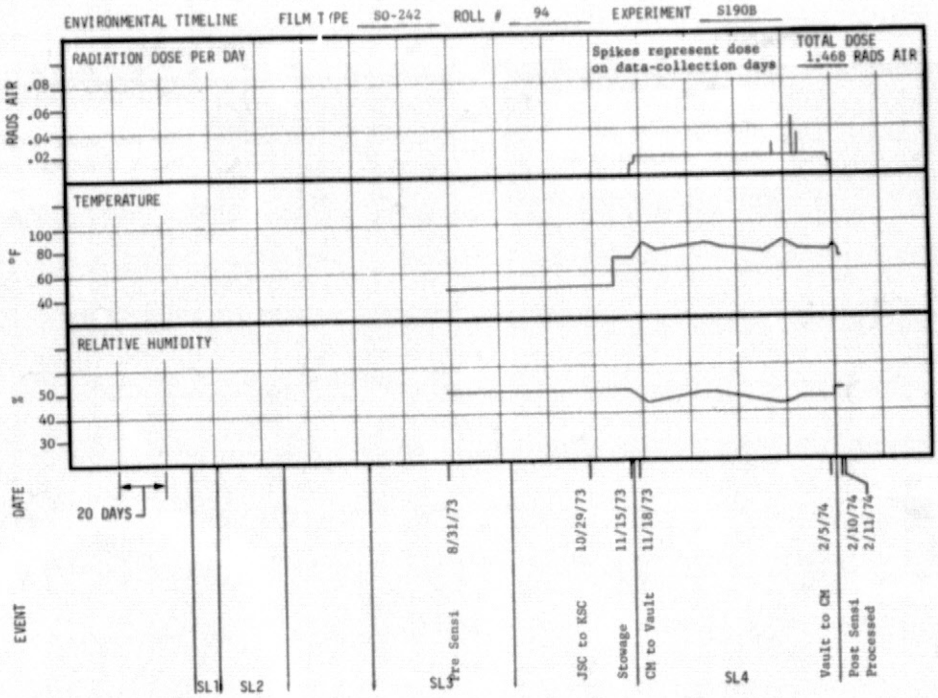


FIGURE D-83, FILM TYPE SO-242, ROLL 90 (cont)



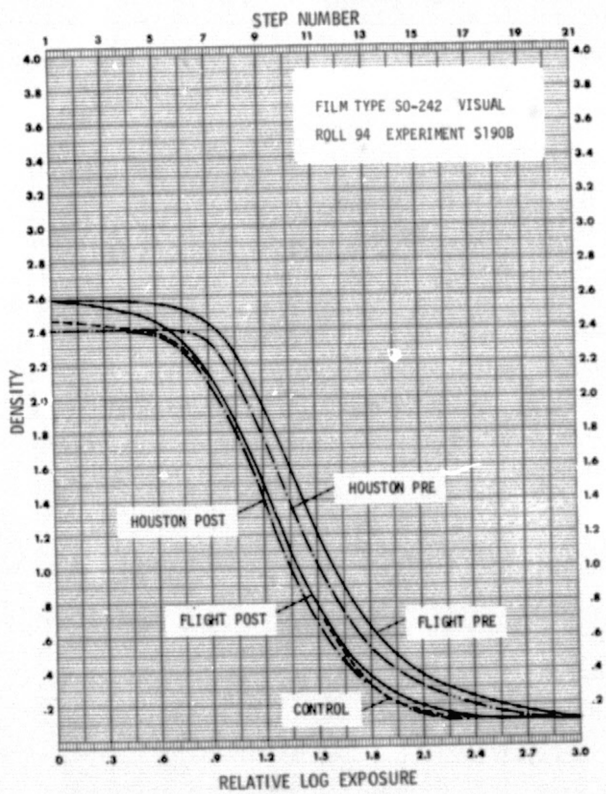
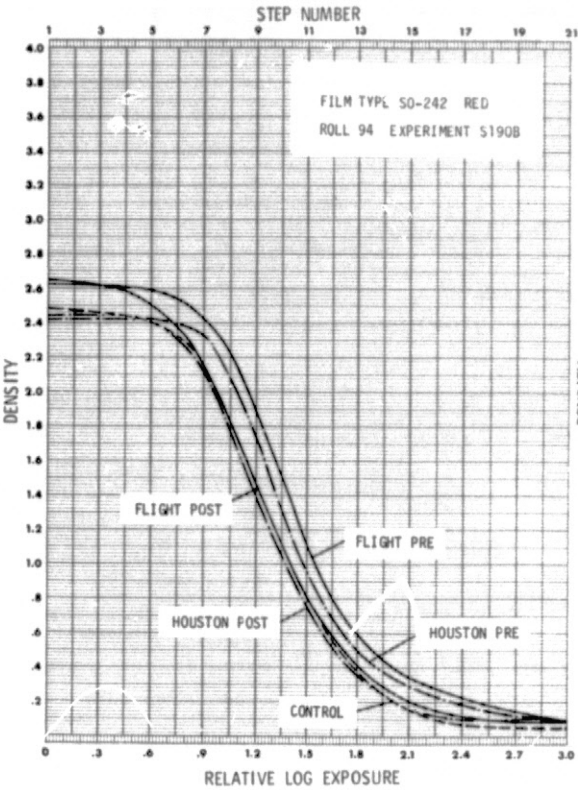
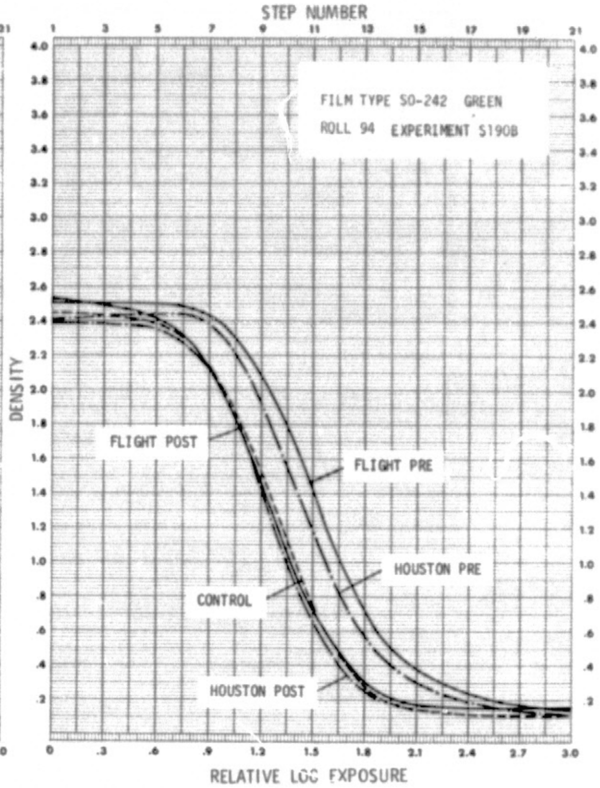


FIGURE D-84, FILM TYPE SO-242, ROLL 94





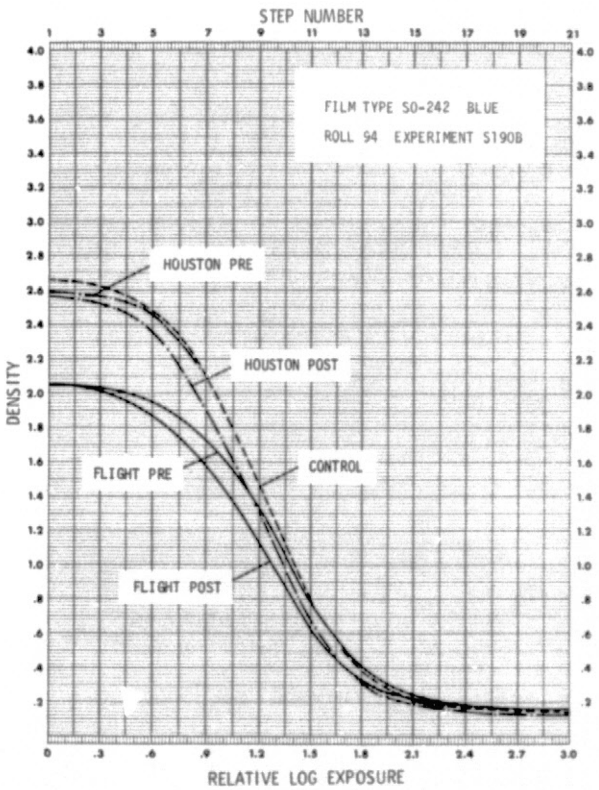
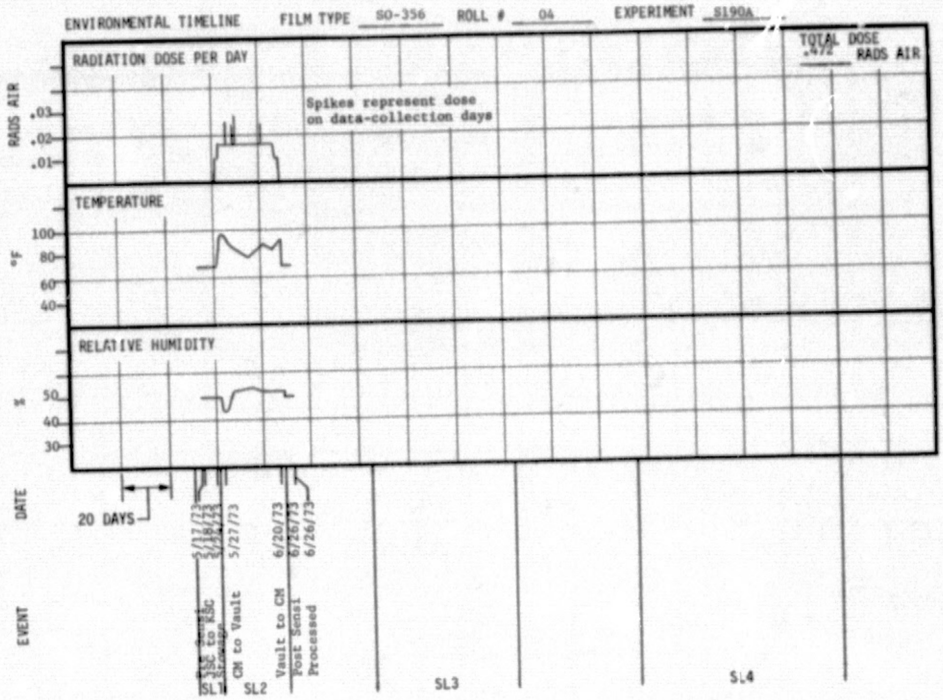


FIGURE D-84, FILM TYPE SO-242, ROLL 94 (cont)



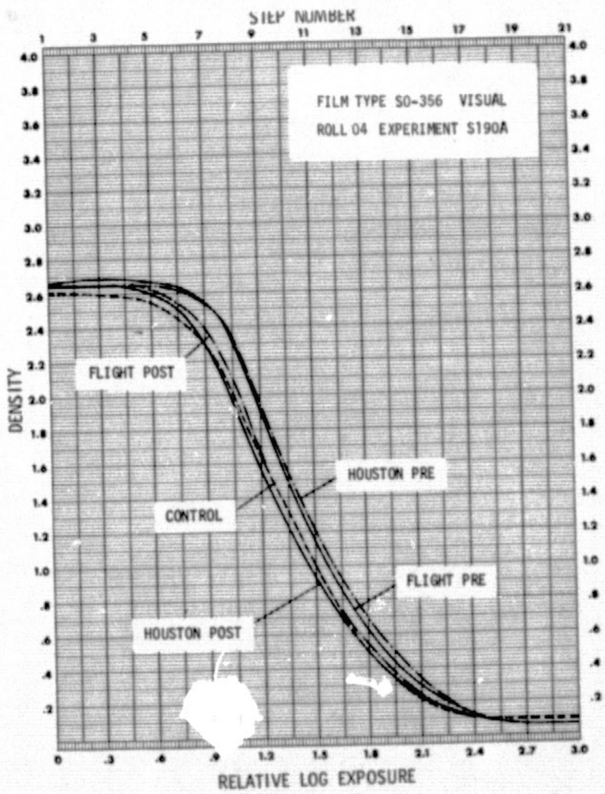
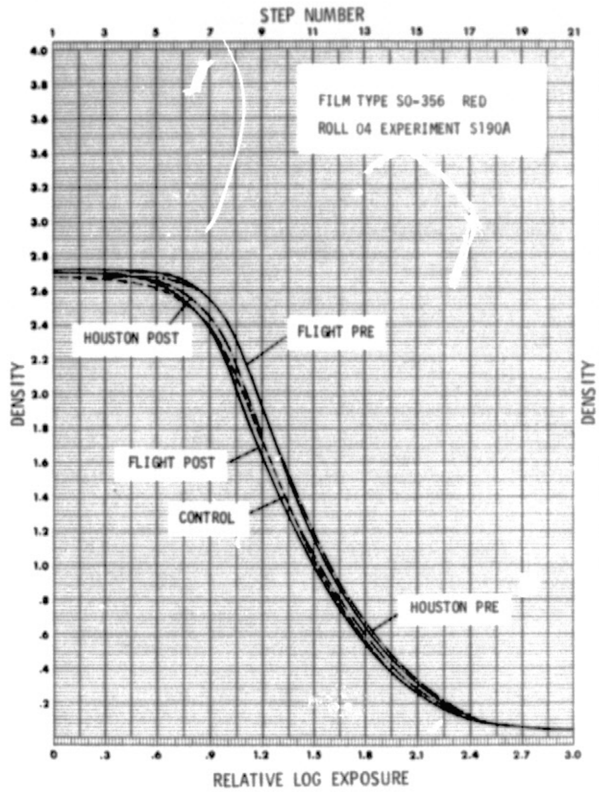
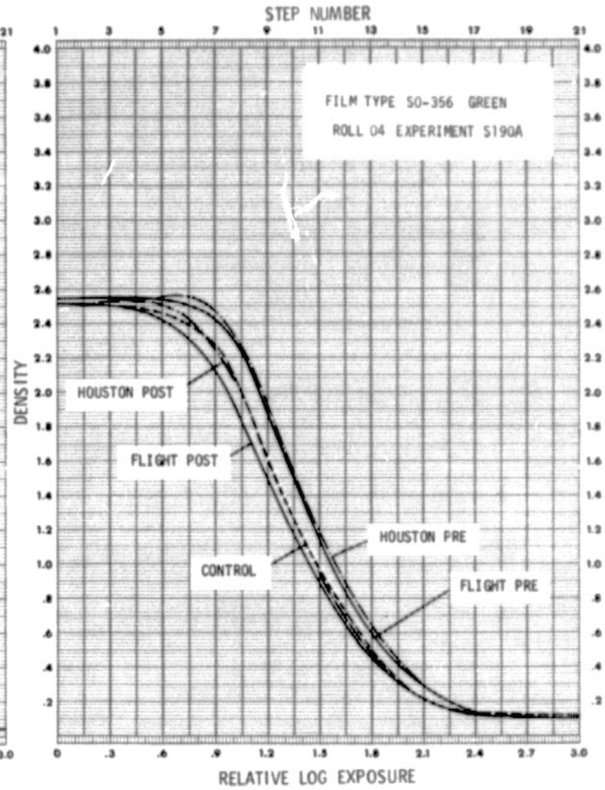


FIGURE D-85, FILM TYPE SO-356, ROLL 04





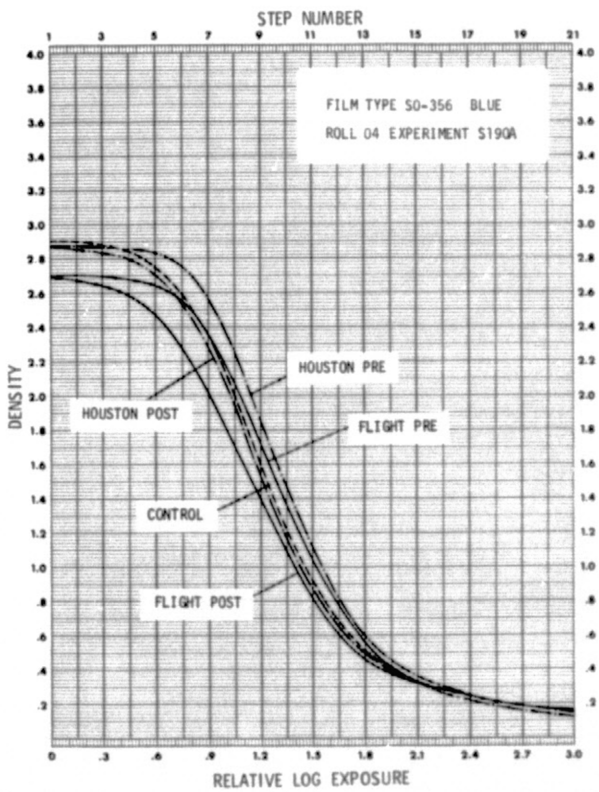
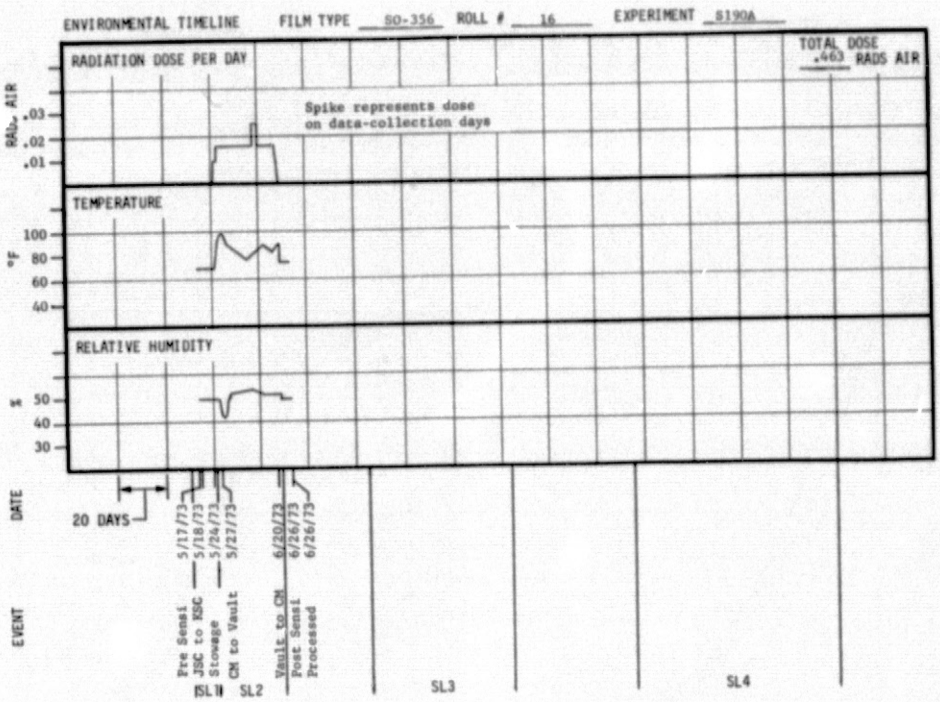


FIGURE D-85, FILM TYPE SO-356, ROLL 04 (cont)



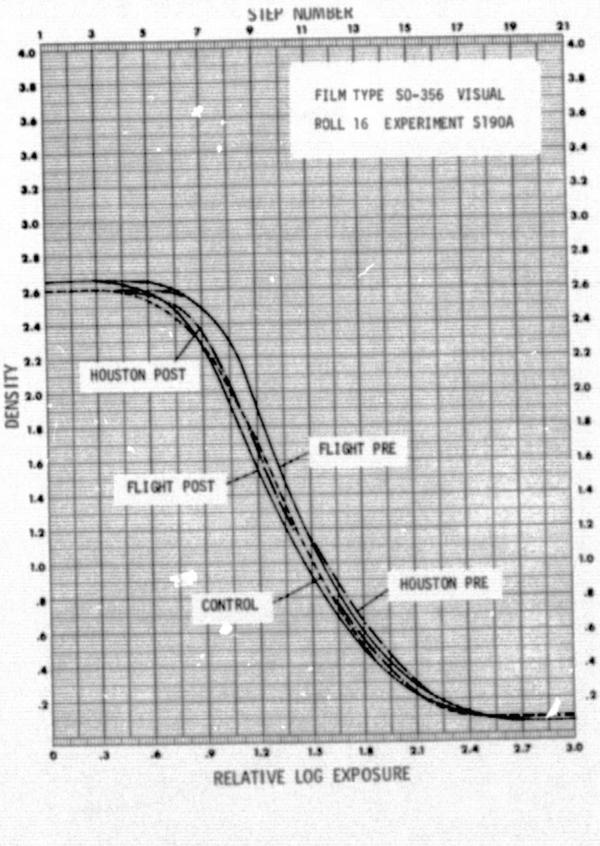
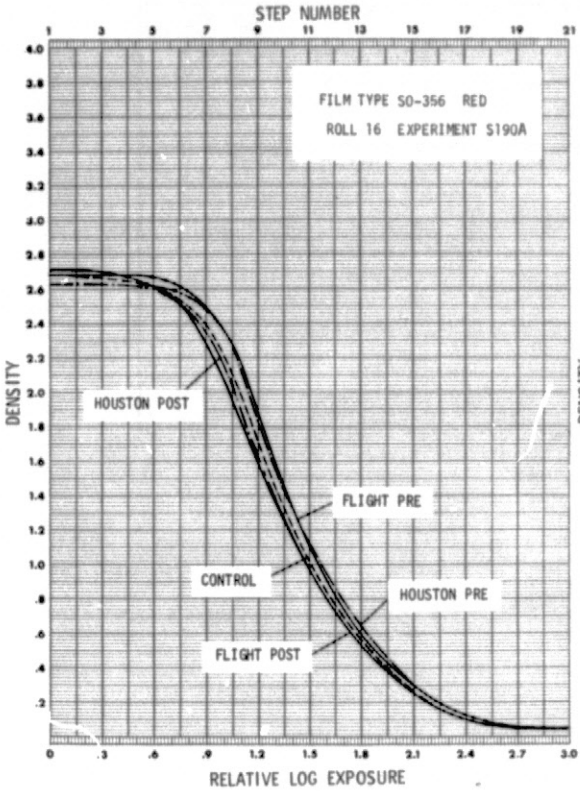
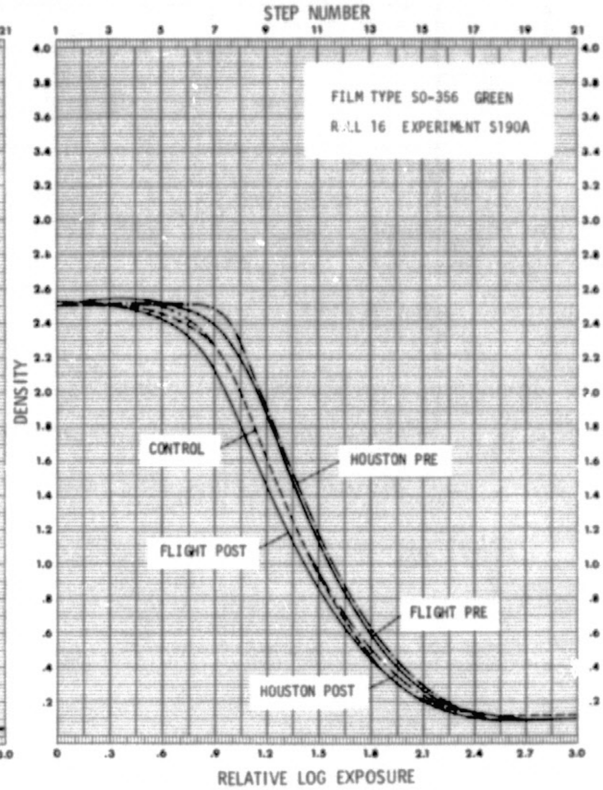


FIGURE D-86, FILM TYPE SO-356, ROLL 16





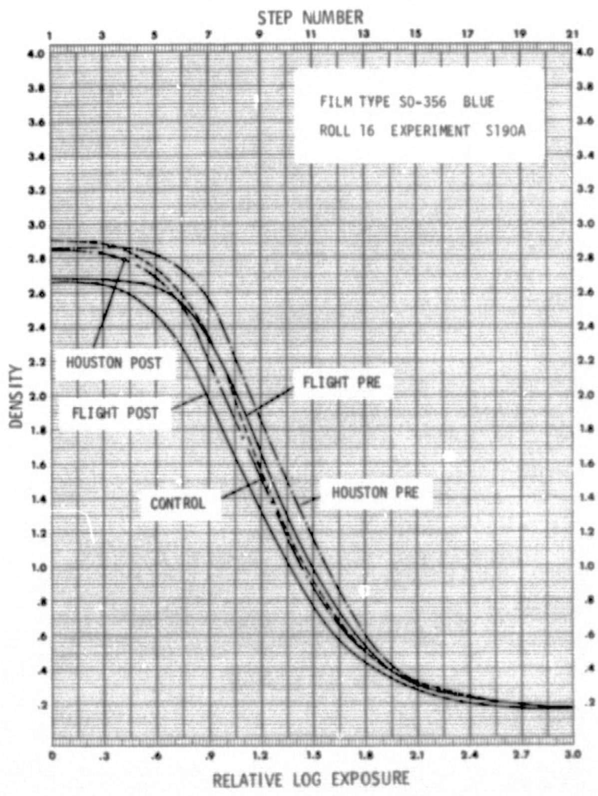
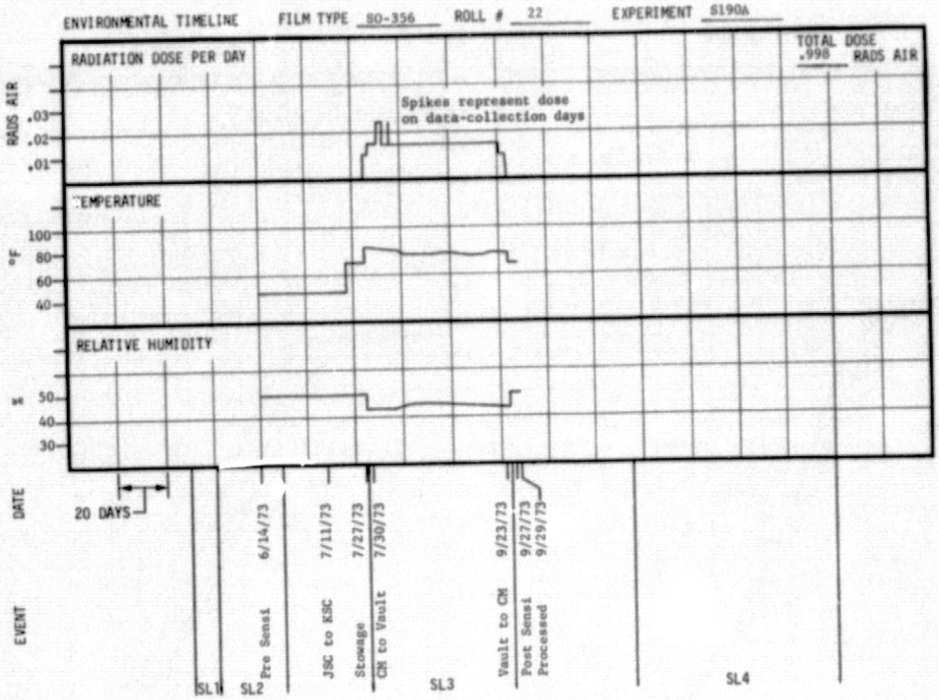


FIGURE D-86, FILM TYPE SO-356, ROLL 16 (cont)



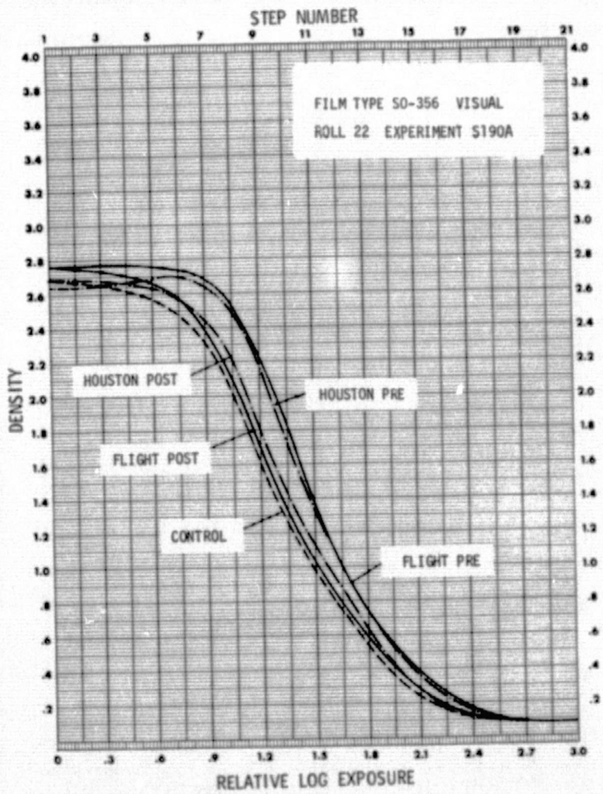
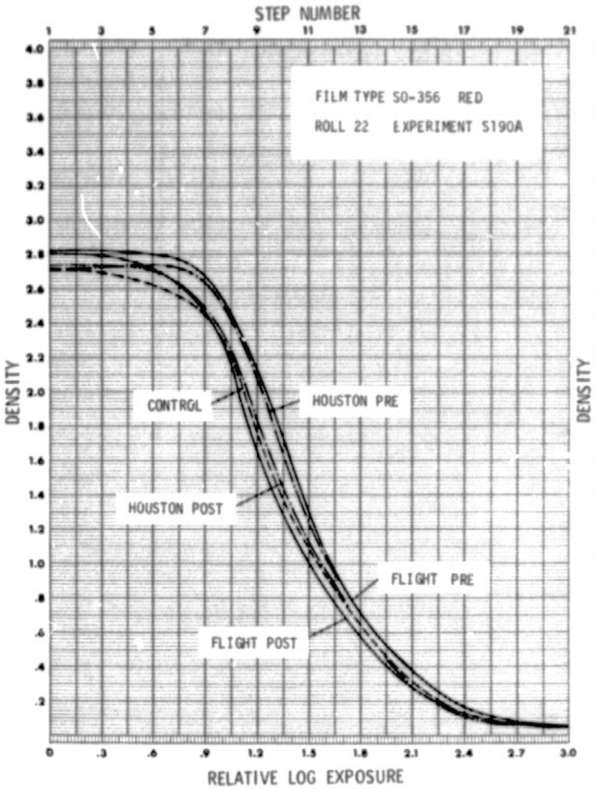
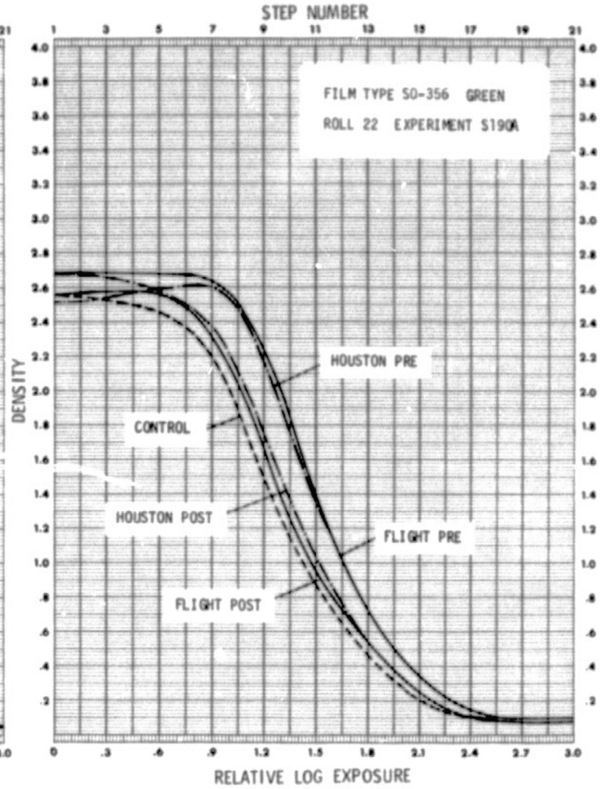


FIGURE D-87. FILM TYPE SO-356, ROLL 22





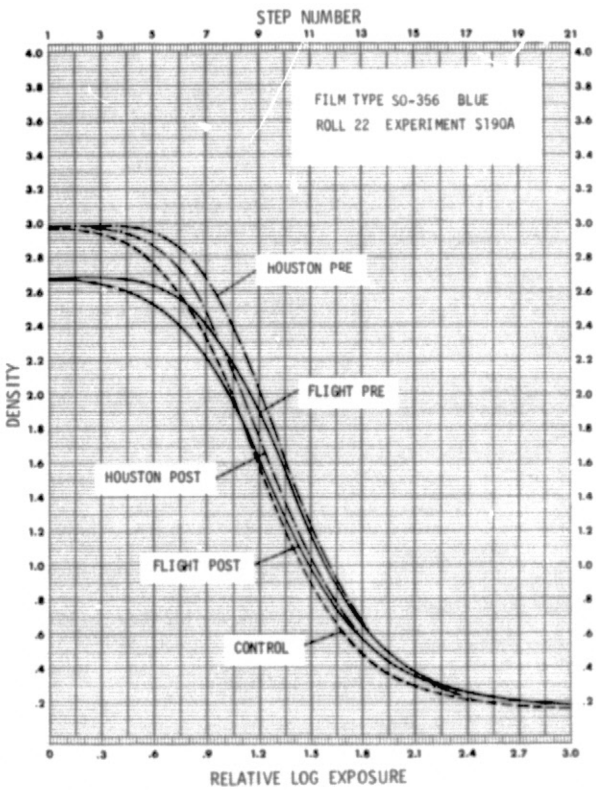
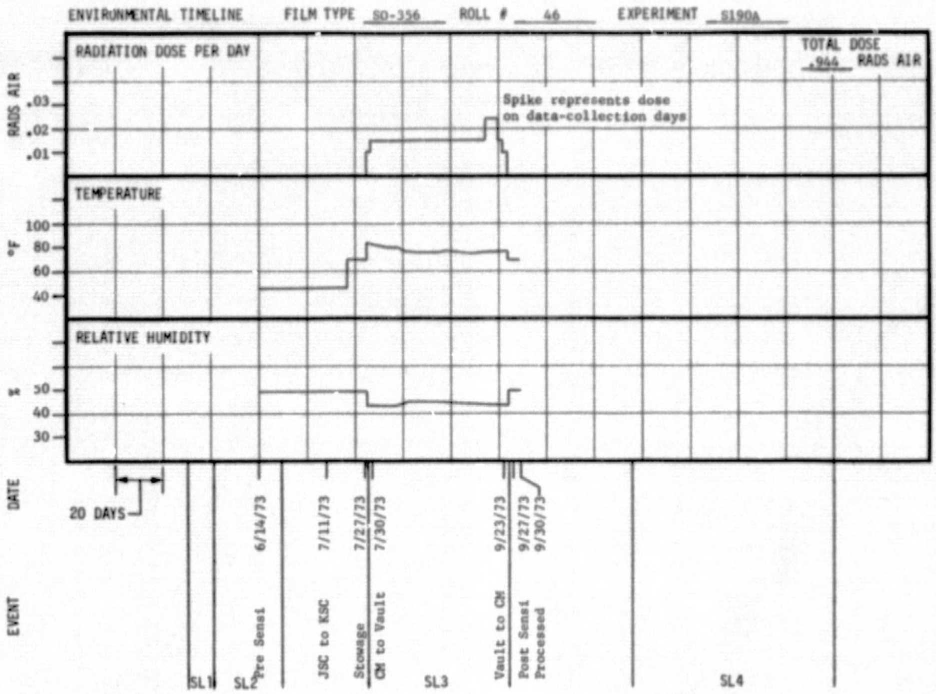


FIGURE D-87, FILM TYPE SO-356, ROLL 22 (cont)



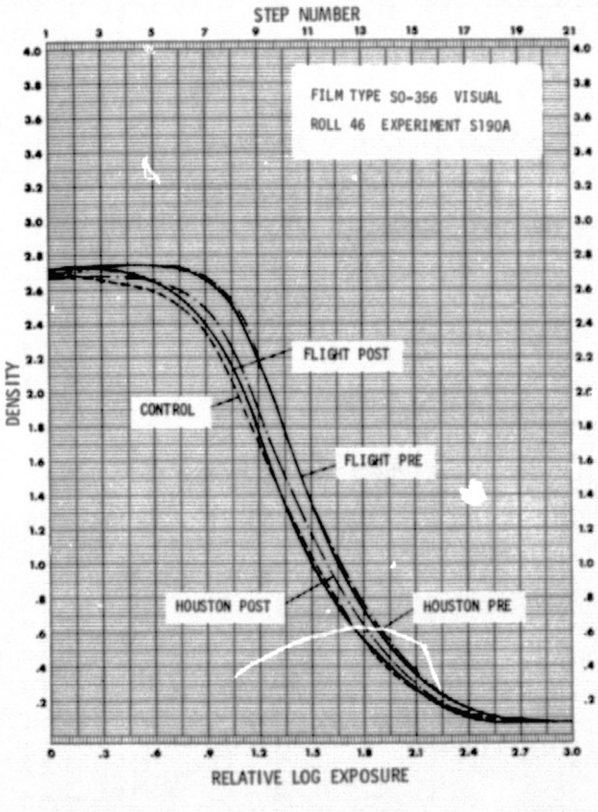
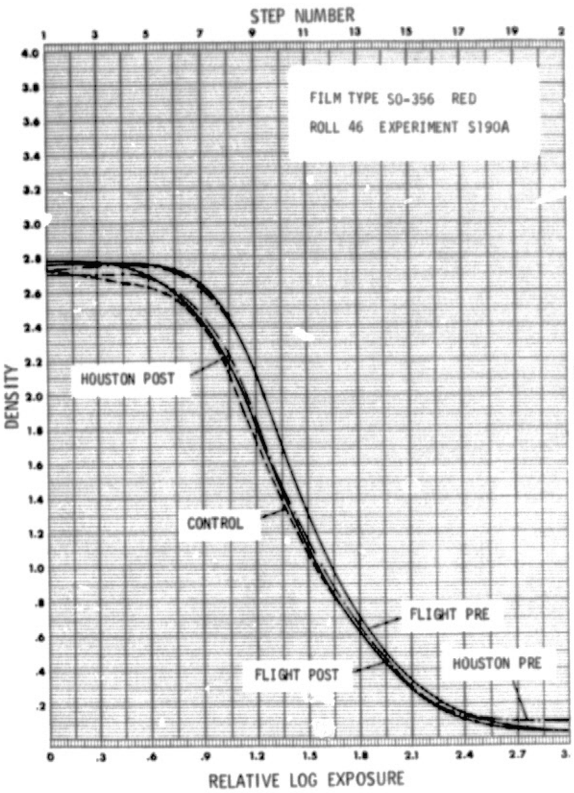
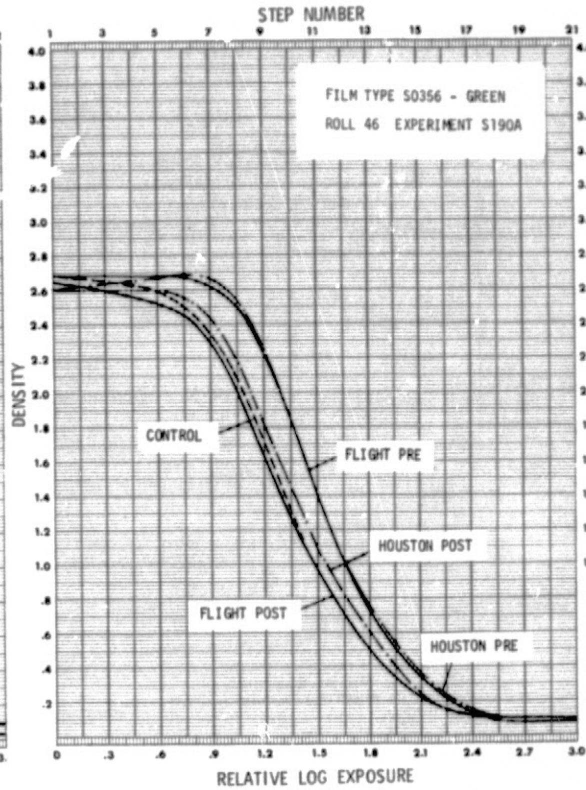


FIGURE D-88, FILM TYPE SO-356, ROLL 46





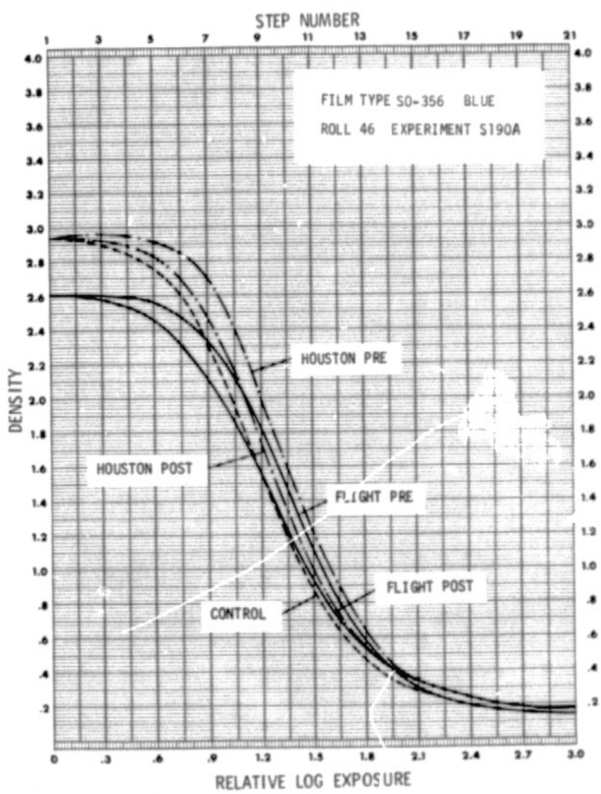
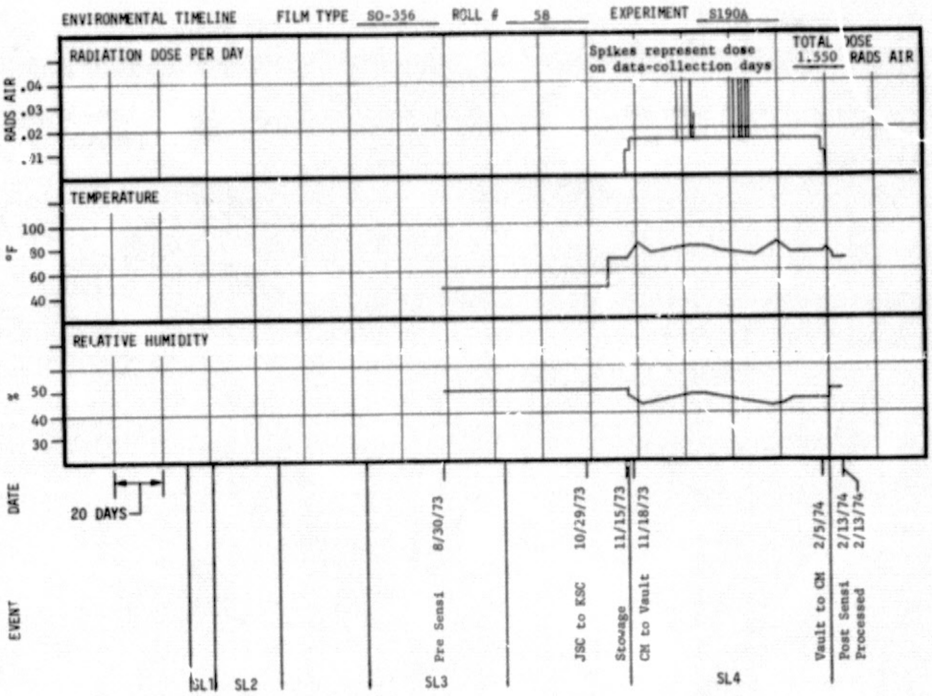


FIGURE D-88, FILM TYPE SO-356, ROLL 46 (cont)



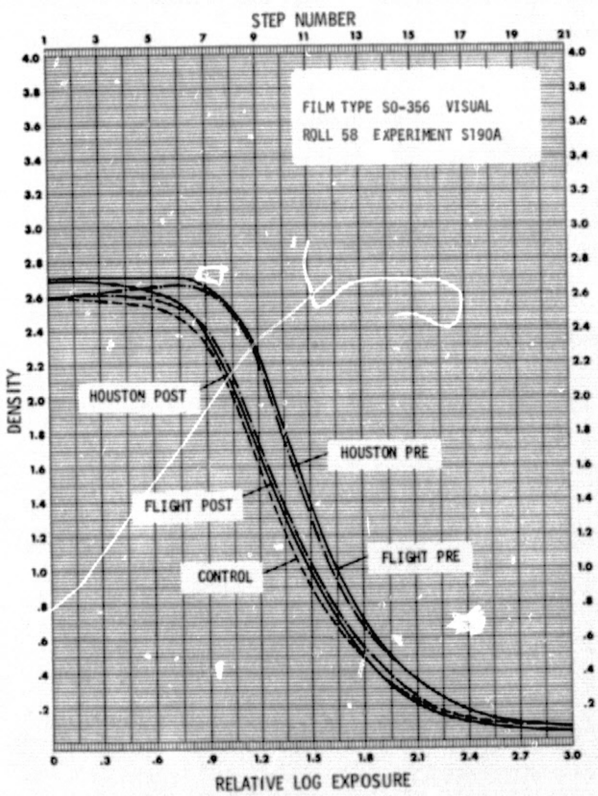
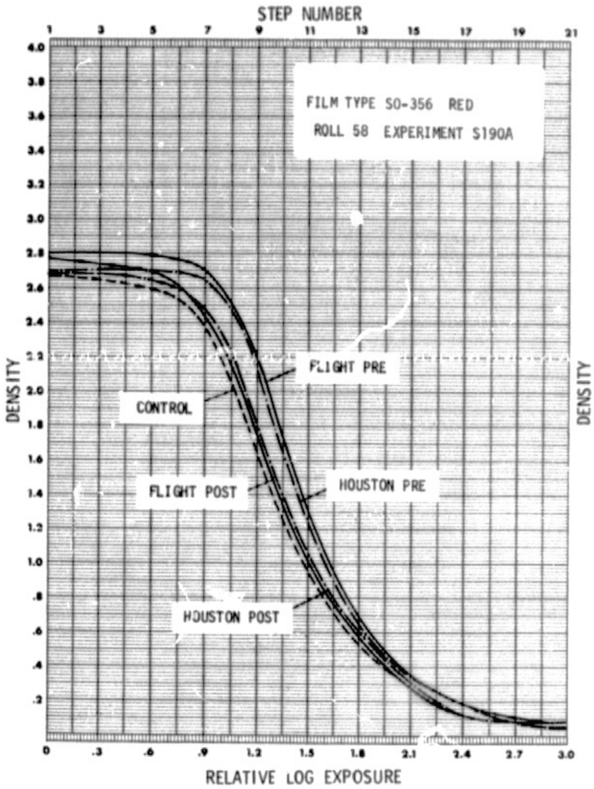
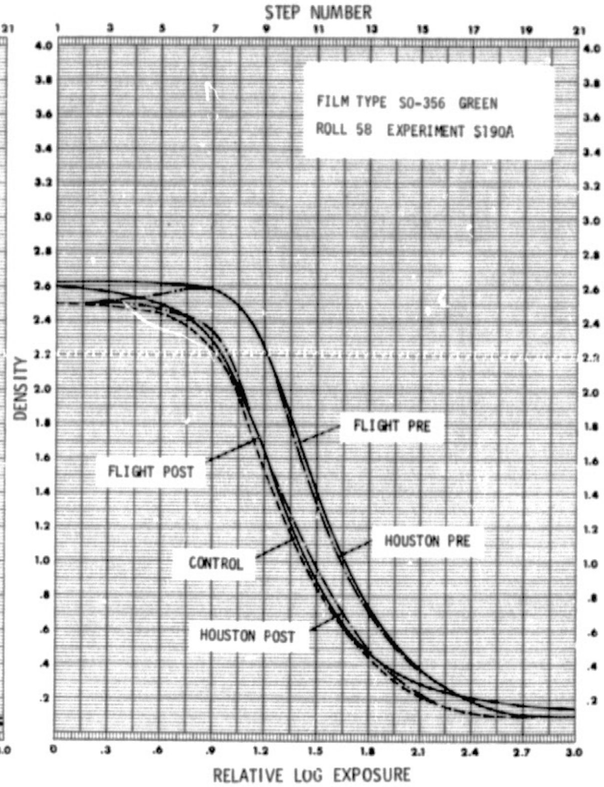


FIGURE D-89, FILM TYPE SO-356, ROLL 58





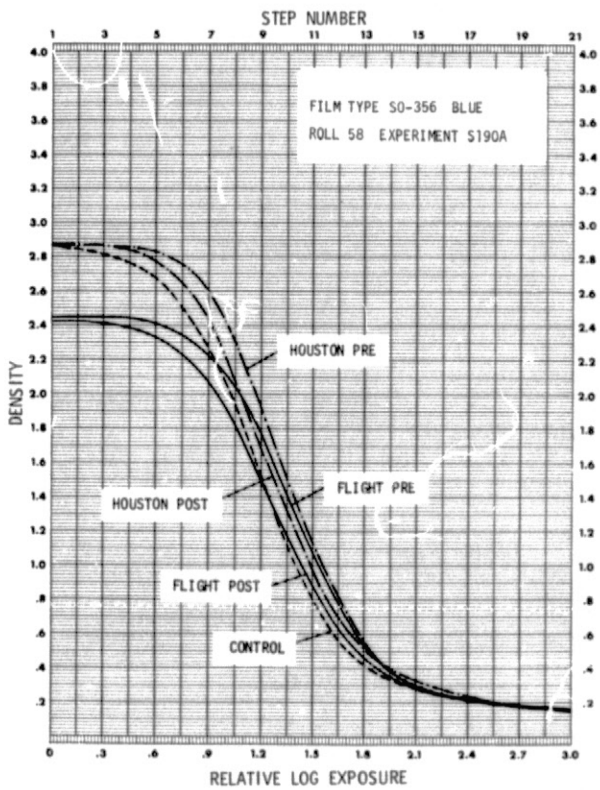
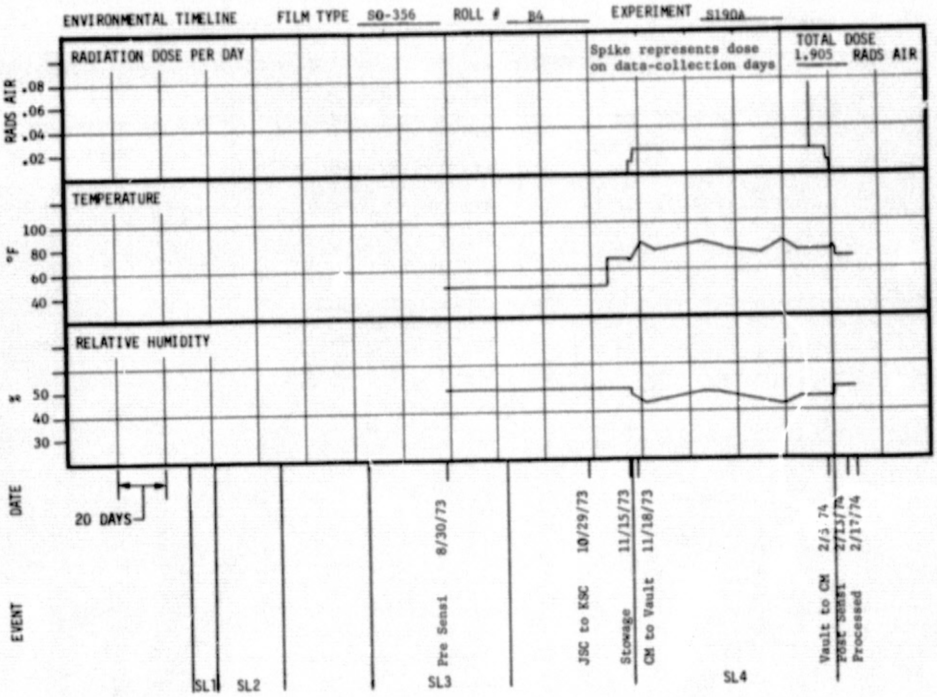


FIGURE D-89, FILM TYPE SO-356, ROLL 58 (cont)



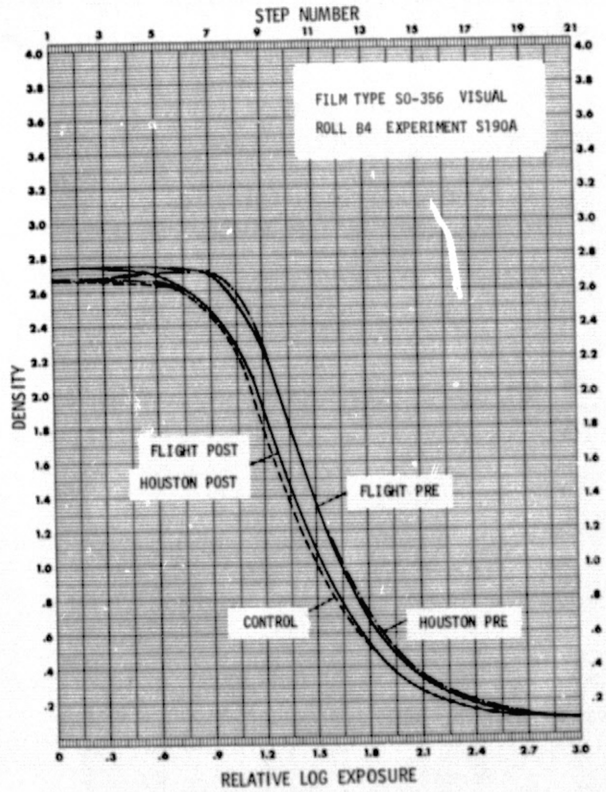


FIGURE D-90, FILM TYPE SO-356, ROLL B4

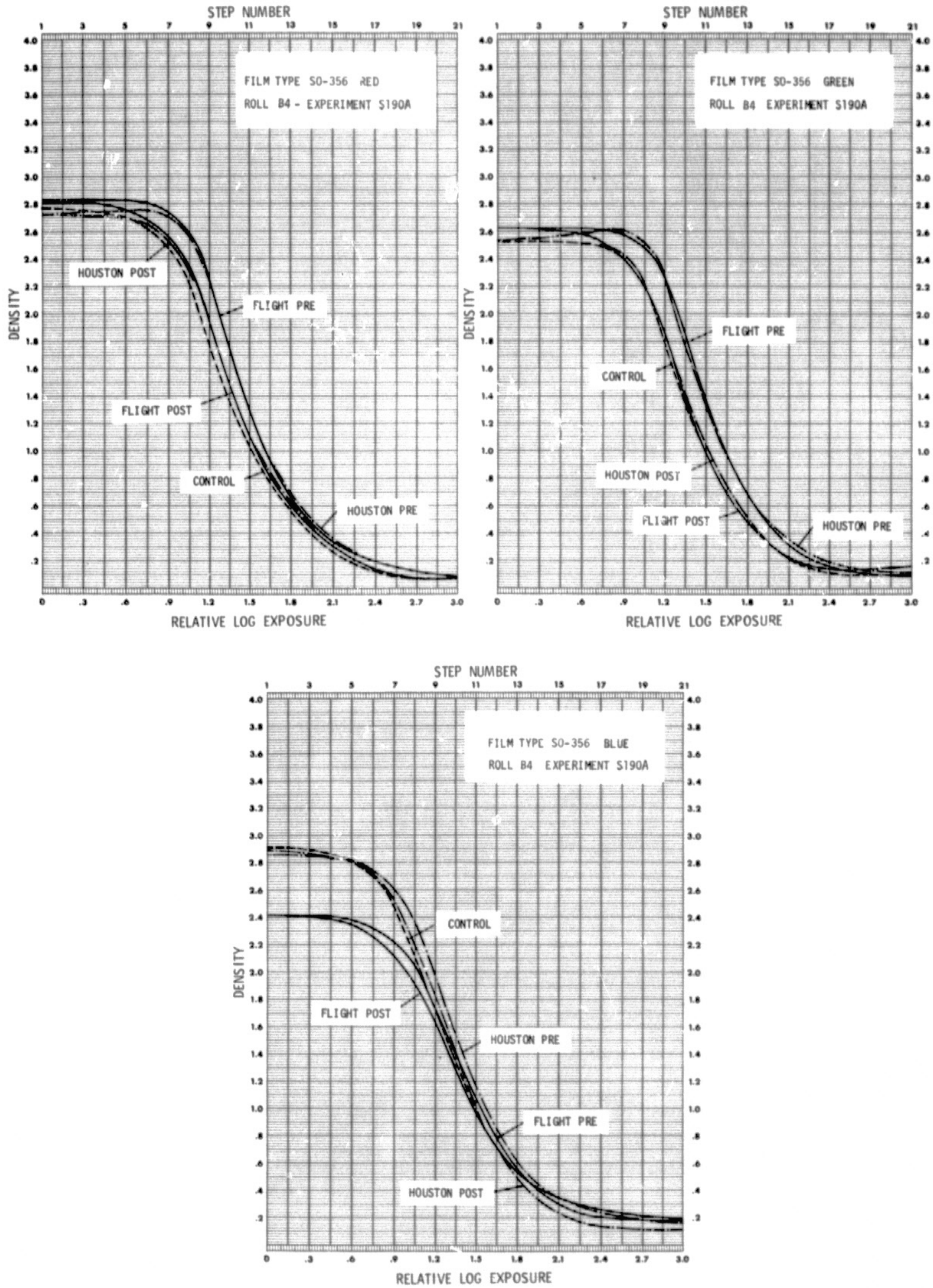
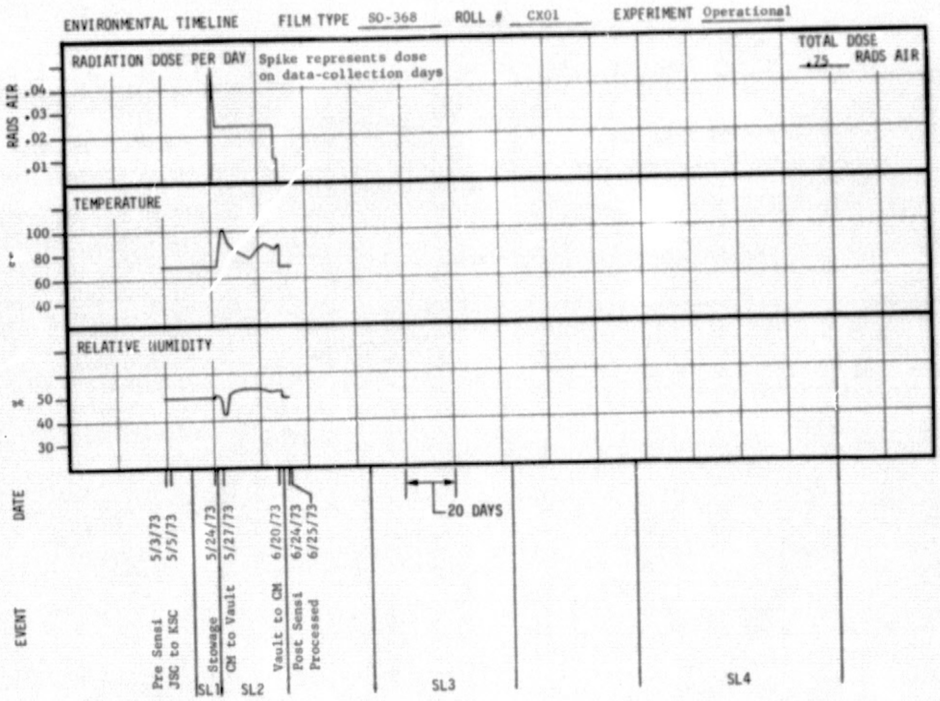


FIGURE D-90, FILM TYPE SO-356, ROLL B4 (cont)



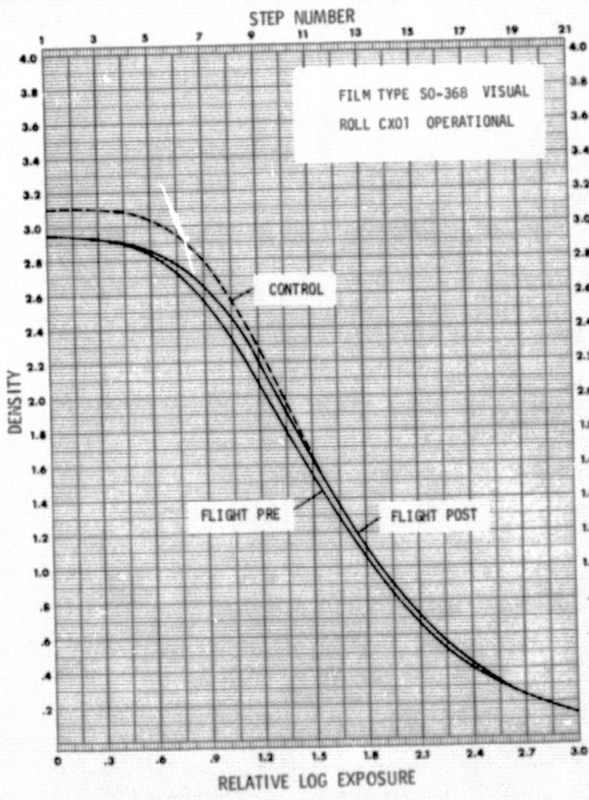
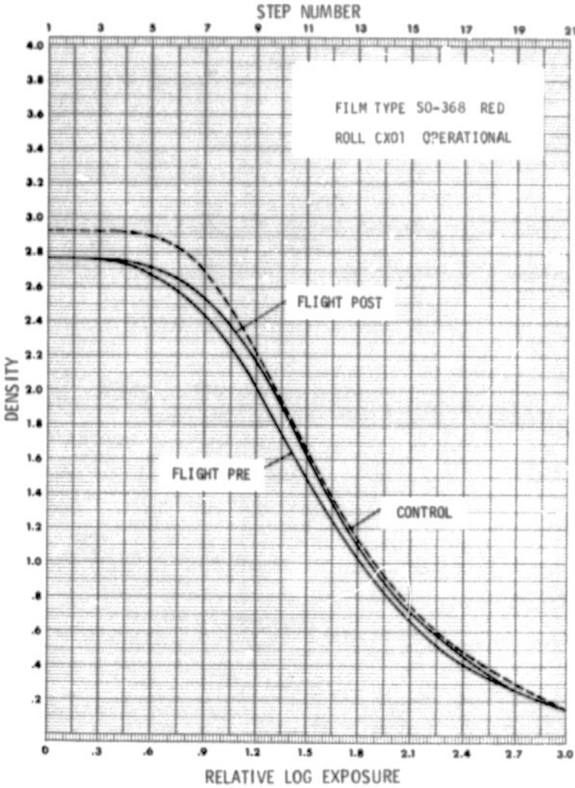
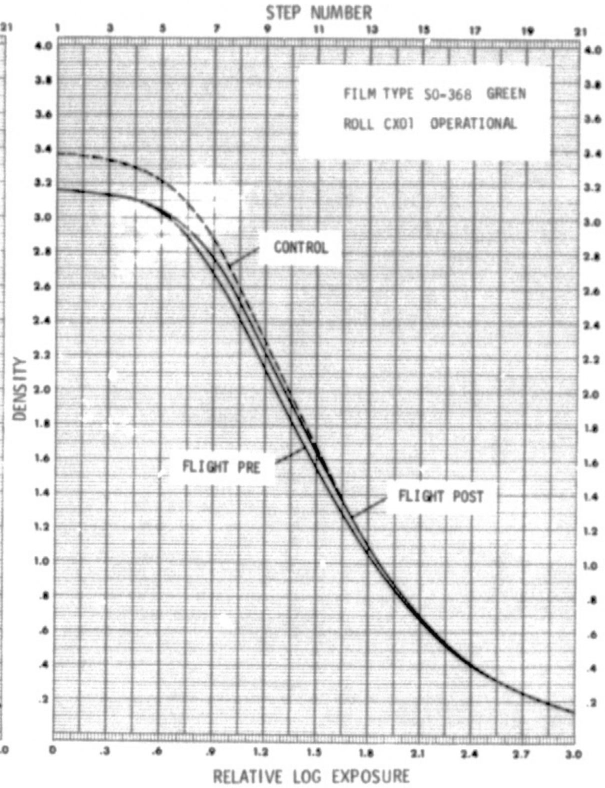


FIGURE D-91, FILM TYPE SO-368, ROLL CX01





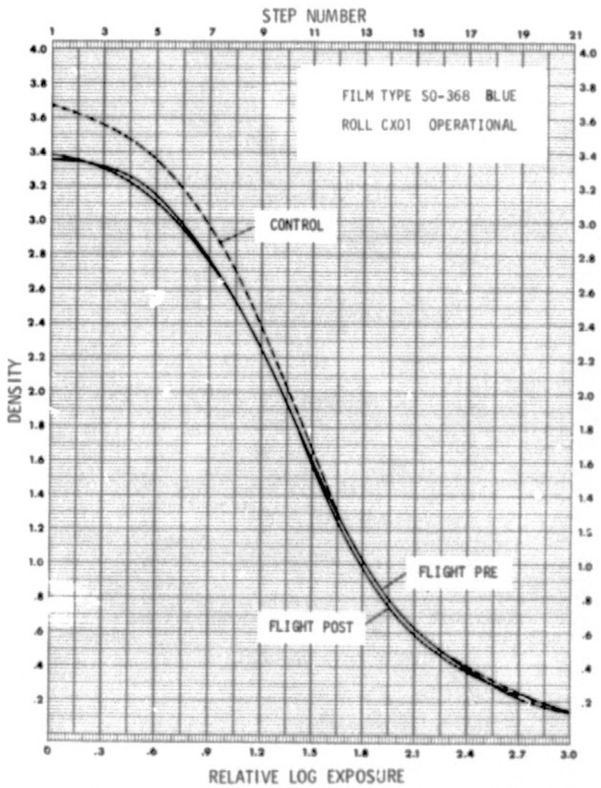
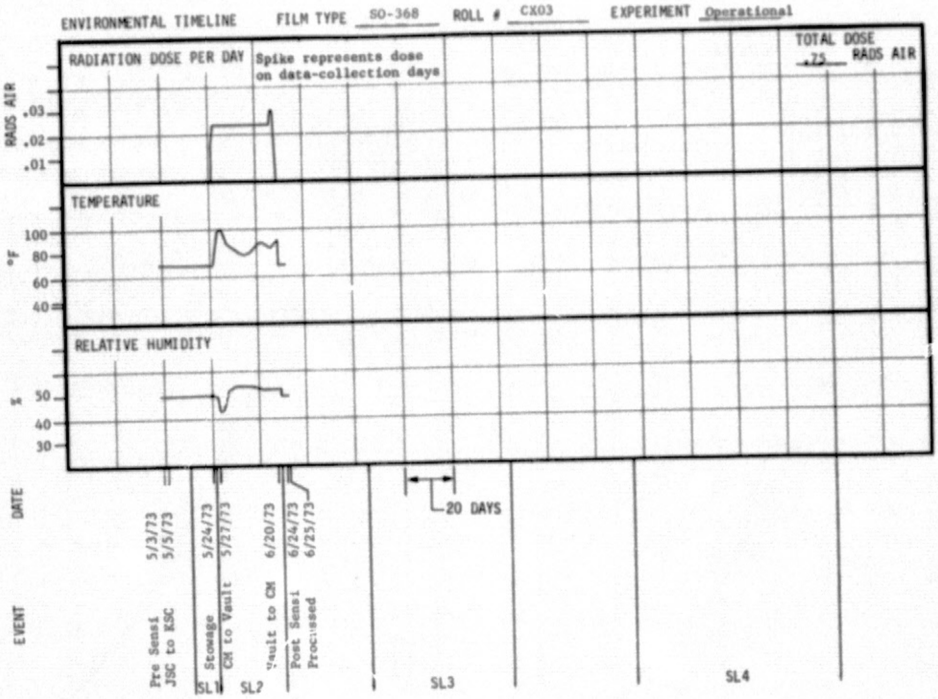


FIGURE D-91, FILM TYPE SO-368, ROLL CX01 (cont)



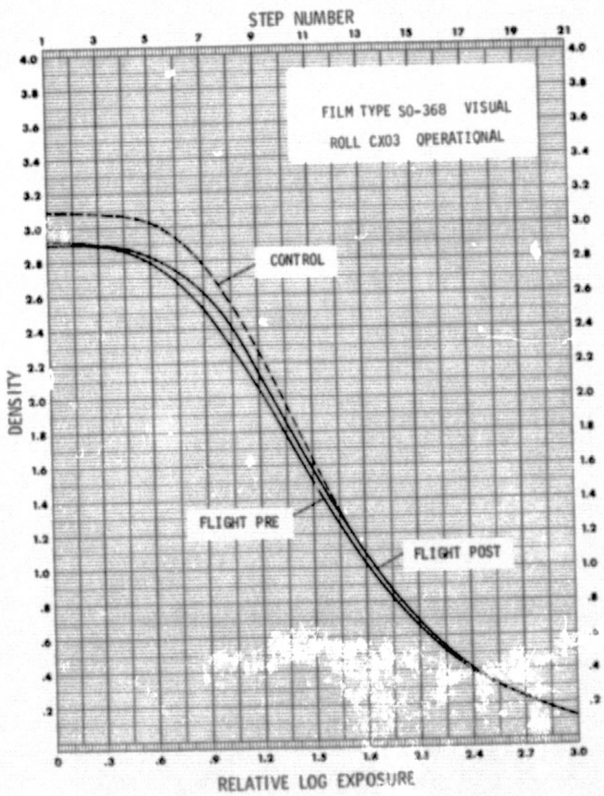
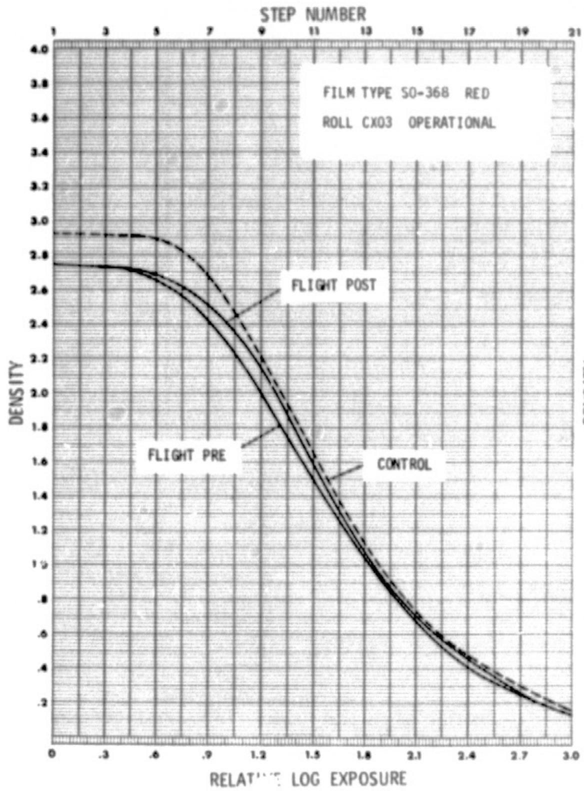
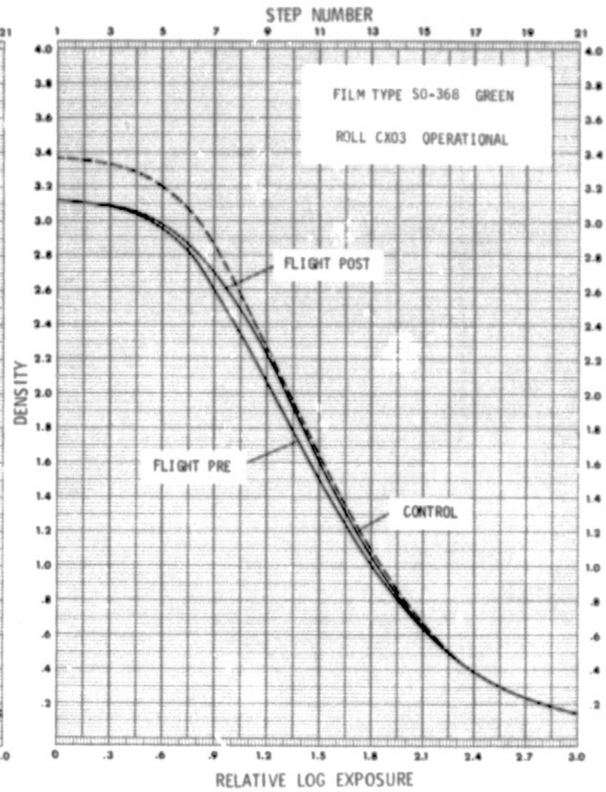


FIGURE D-92, FILM TYPE SO-368, ROLL CX03





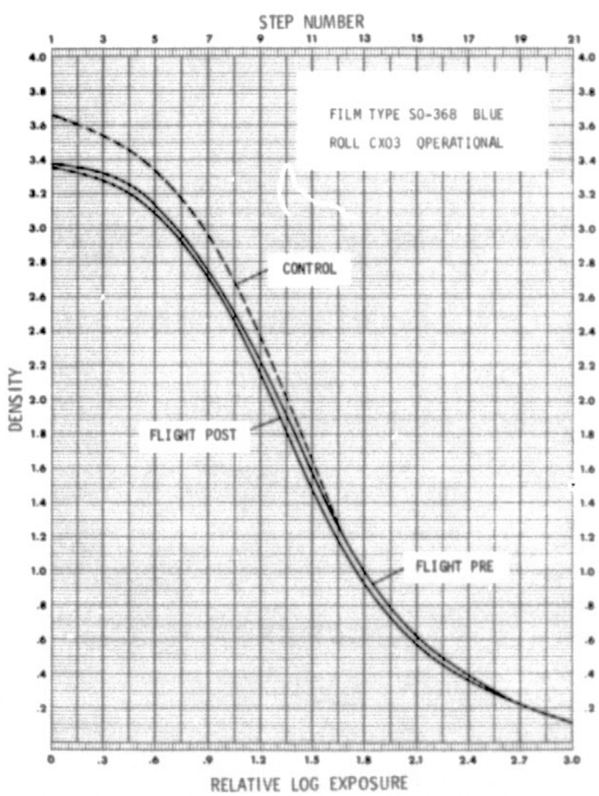
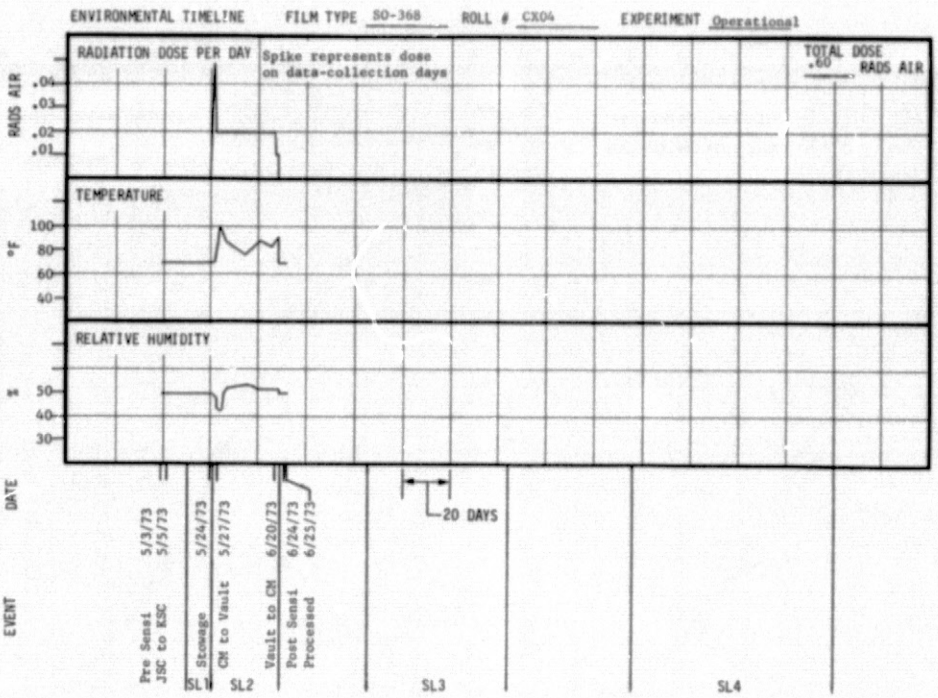


FIGURE D-92, FILM TYPE SO-368, ROLL CX03 (cont)



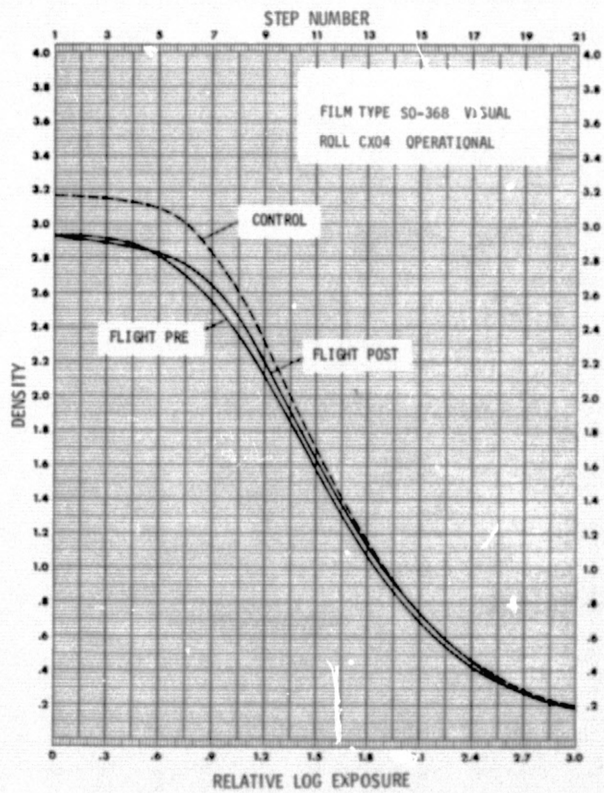


FIGURE D-92, FILM TYPE SO-368, ROLL CX04

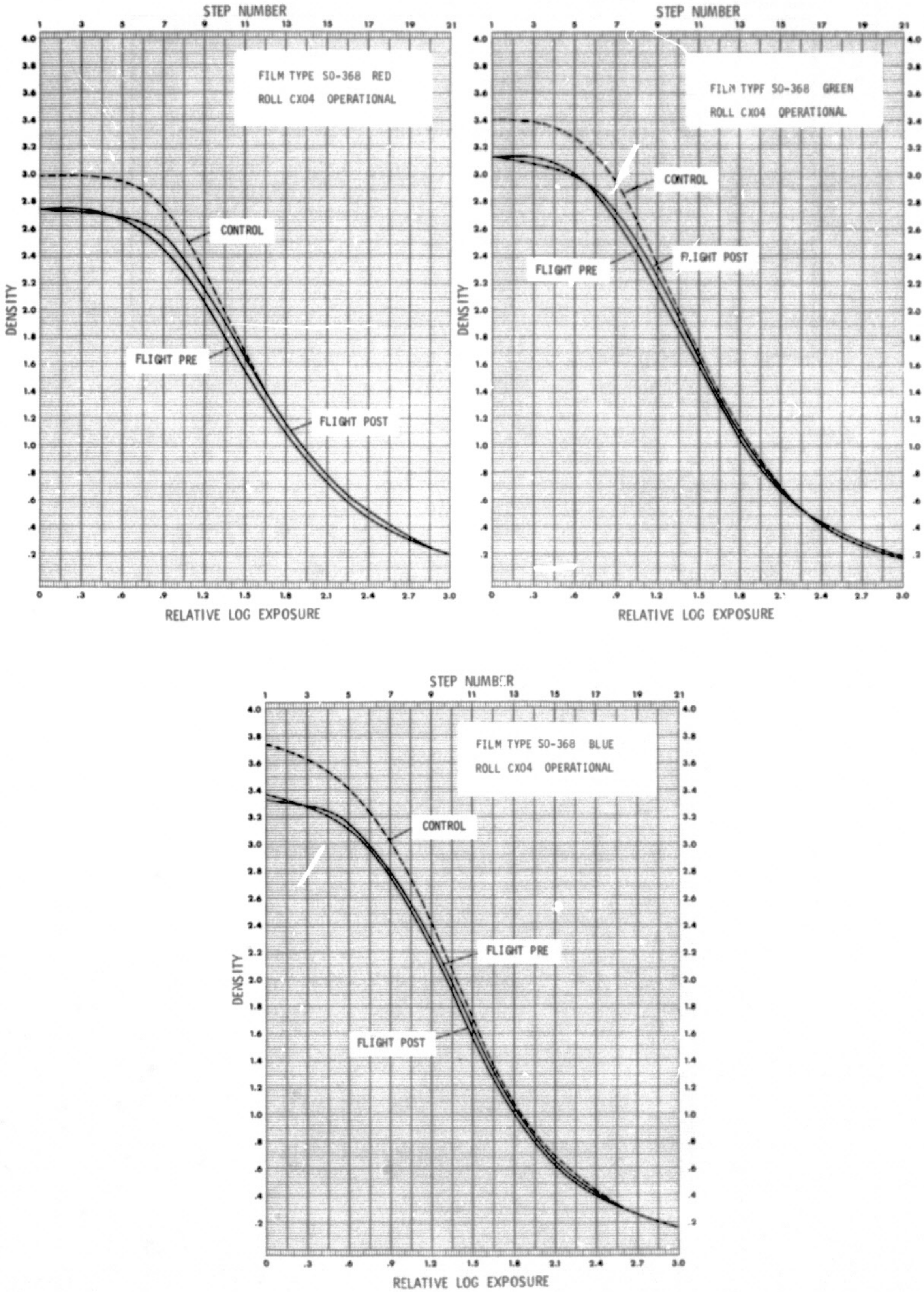
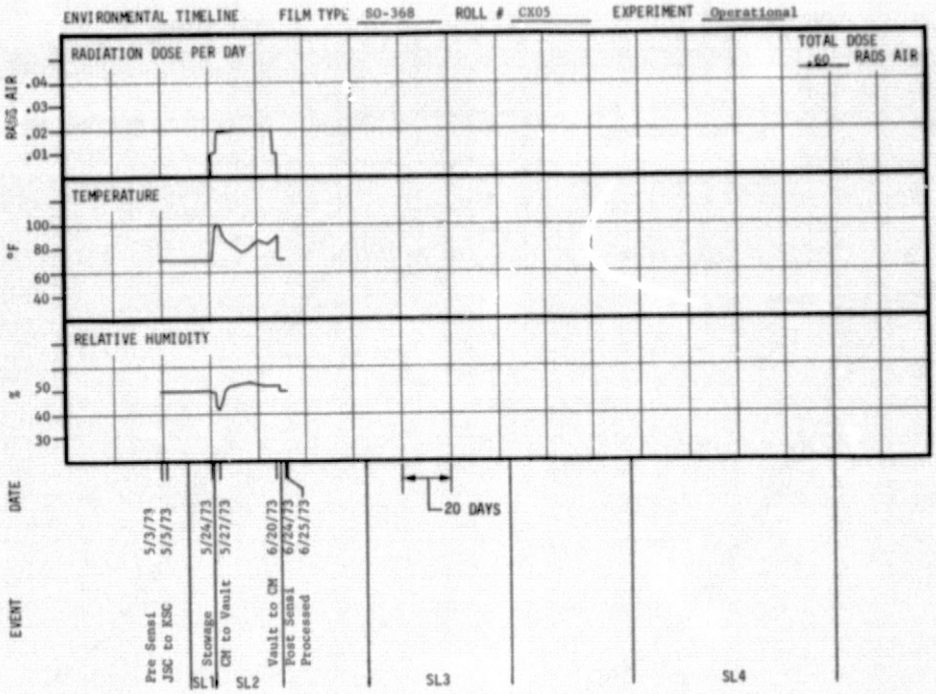


FIGURE D-93, FILM TYPE SO-368, ROLL CX04 (cont)



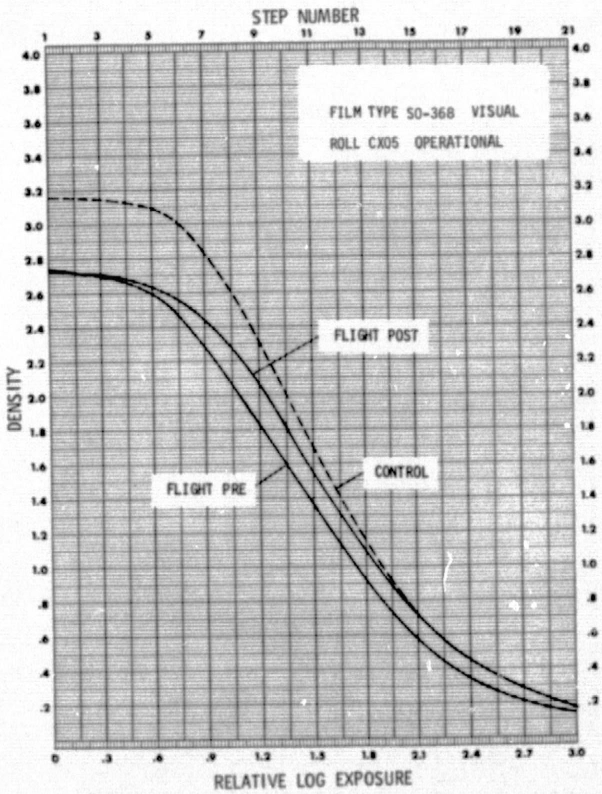
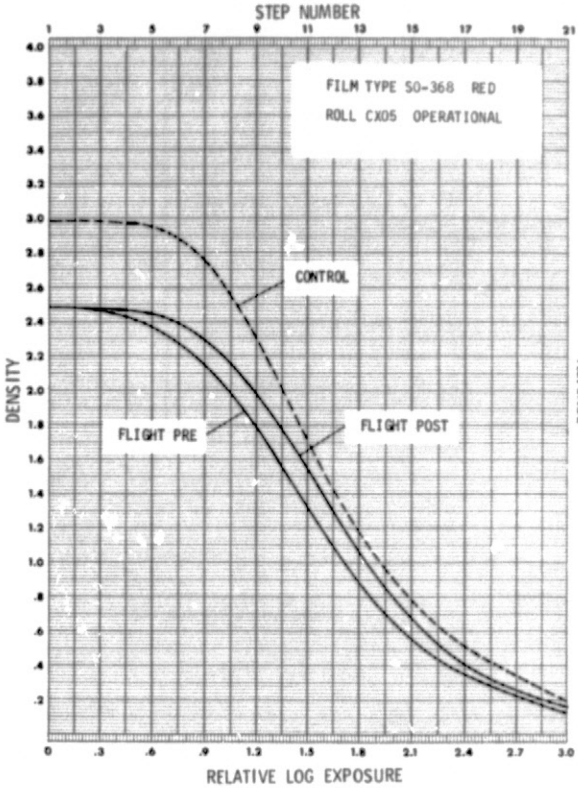
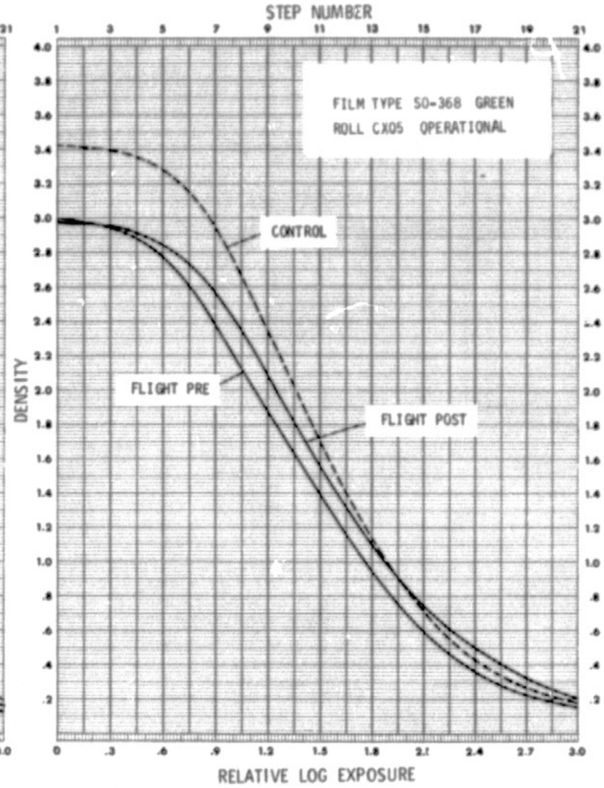


FIGURE D-94, FILM TYPE SO-368, ROLL CX05





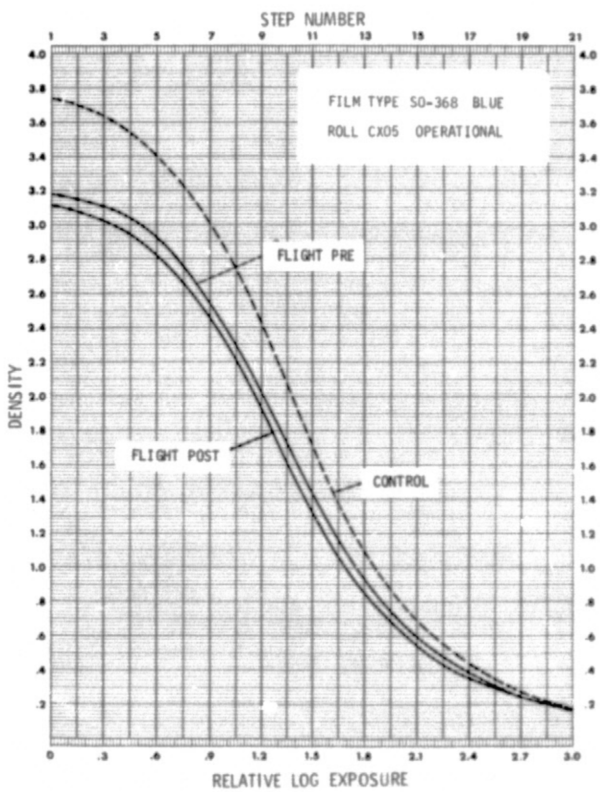
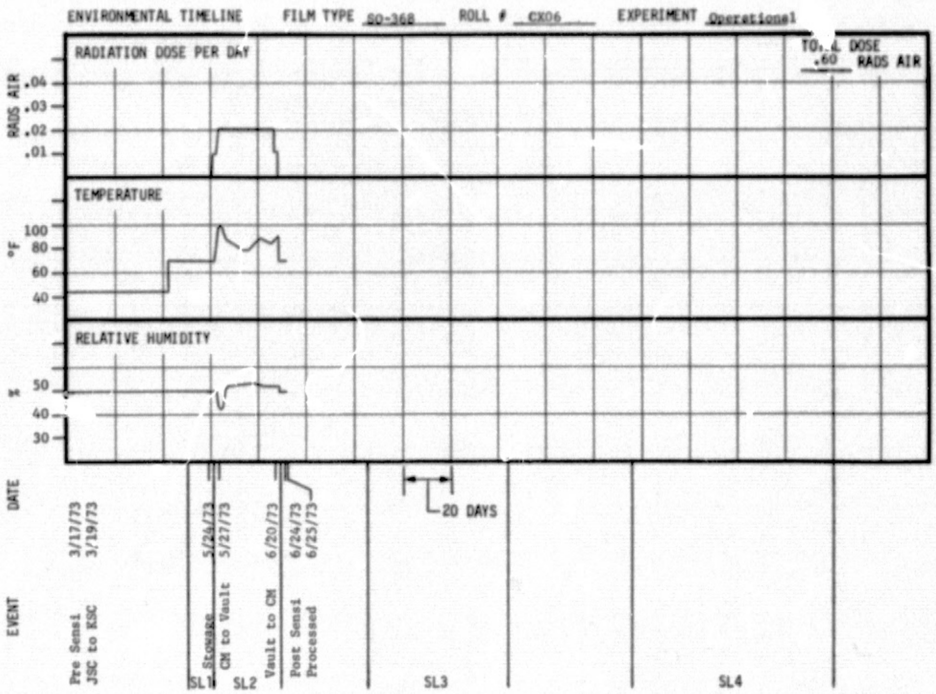


FIGURE D-94, FILM TYPE SO-368, ROLL CX05 (cont)



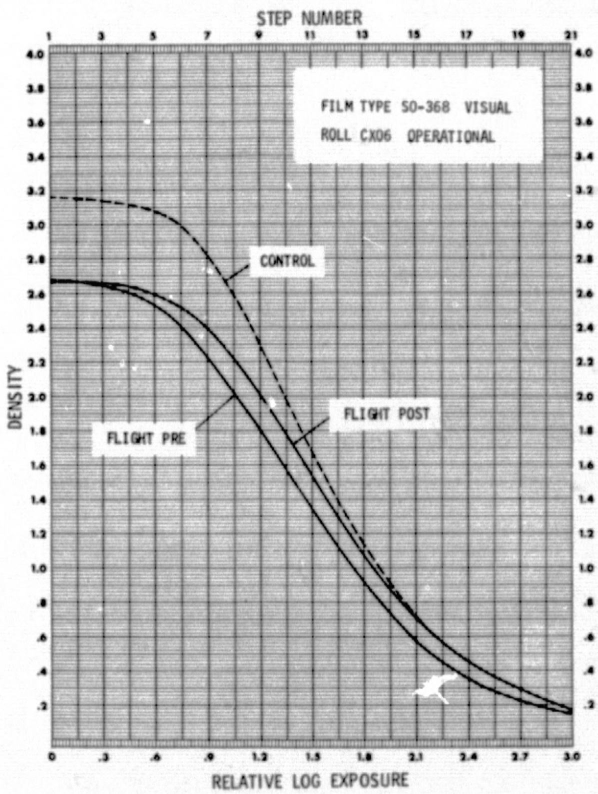
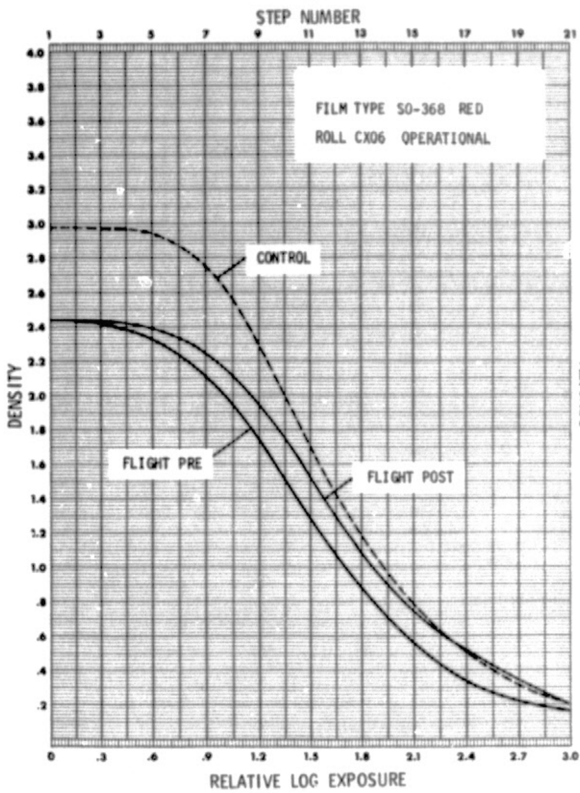
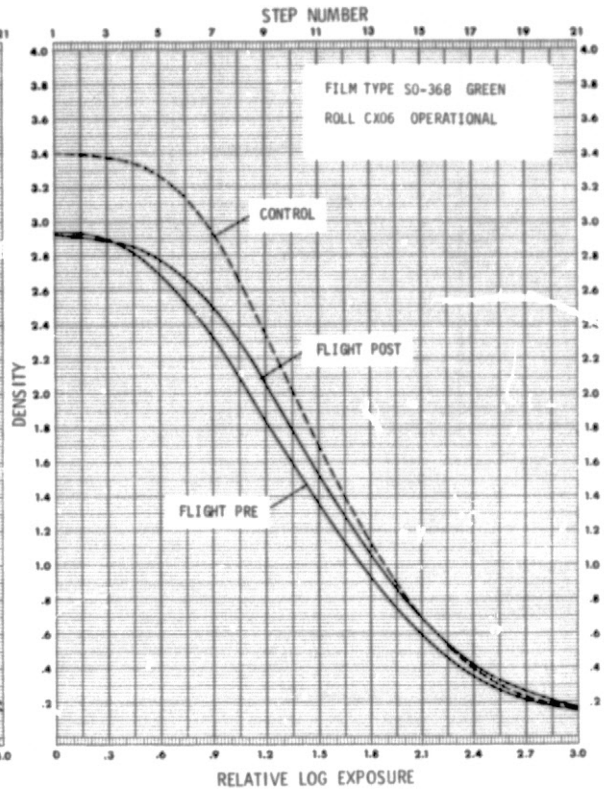


FIGURE D-95, FILM TYPE SO-368, ROLL CX06





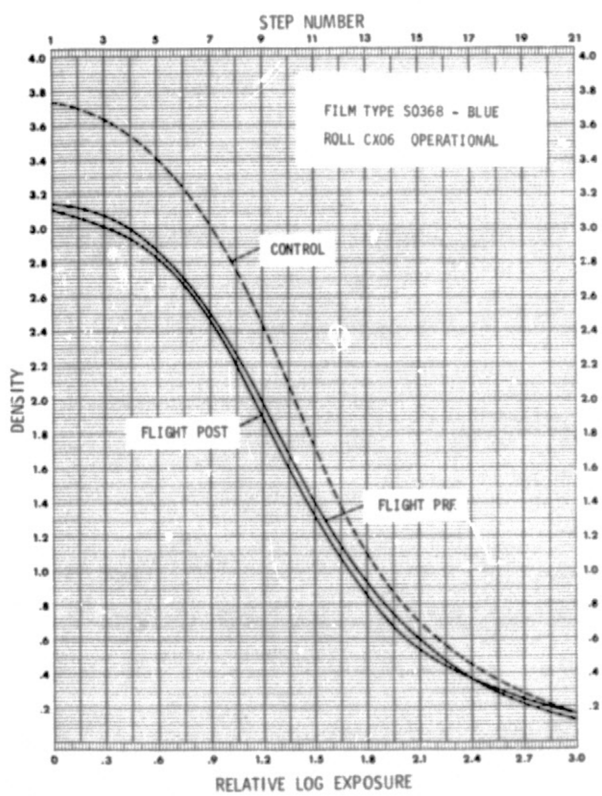
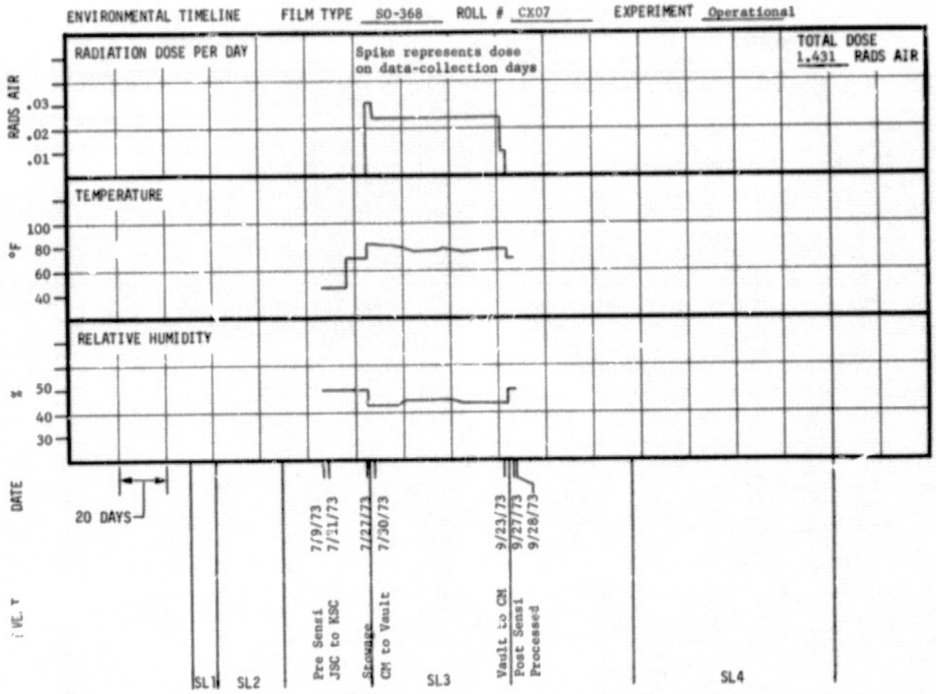


FIGURE D-95, FILM TYPE SO-368, ROLL CX06 (cont)



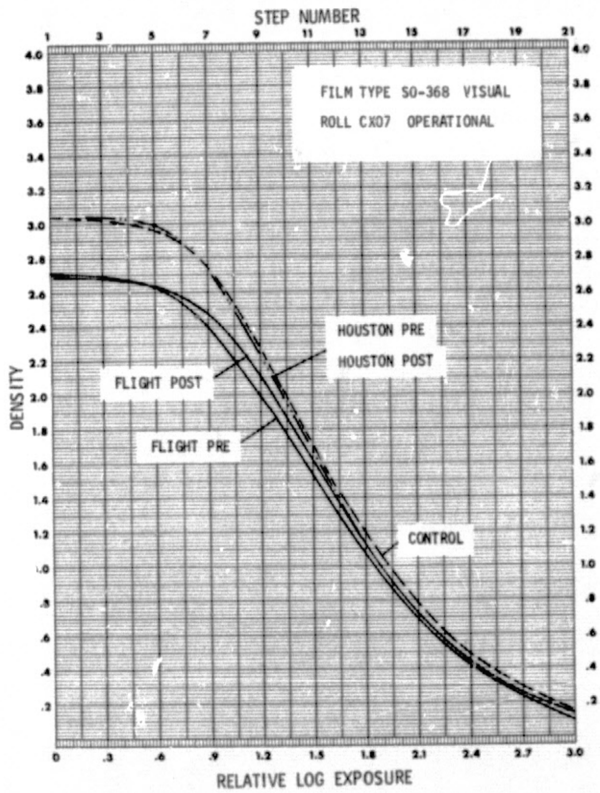
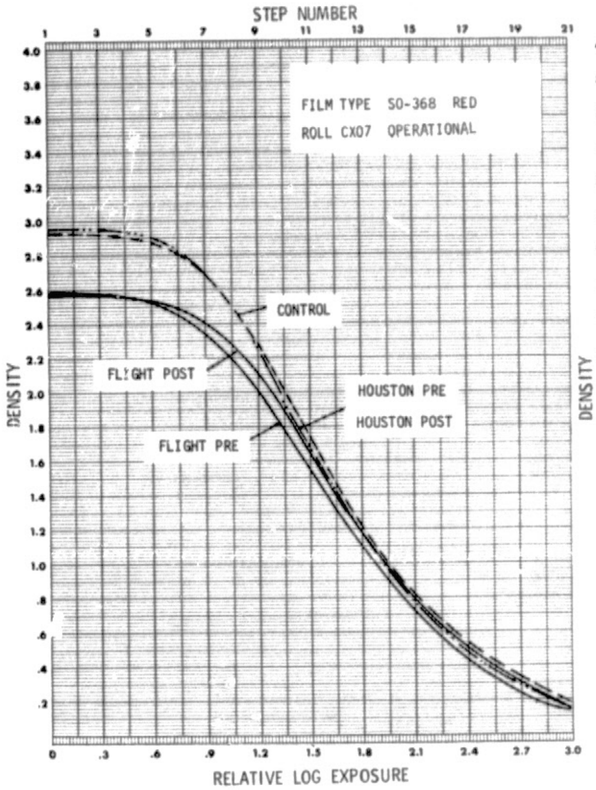
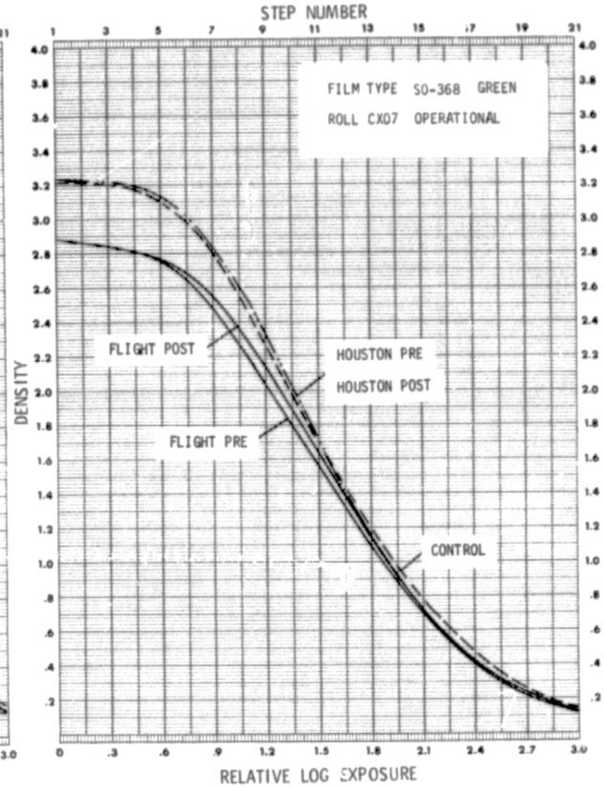


FIGURE D-96, FILM TYPE SO-368, ROLL CX07





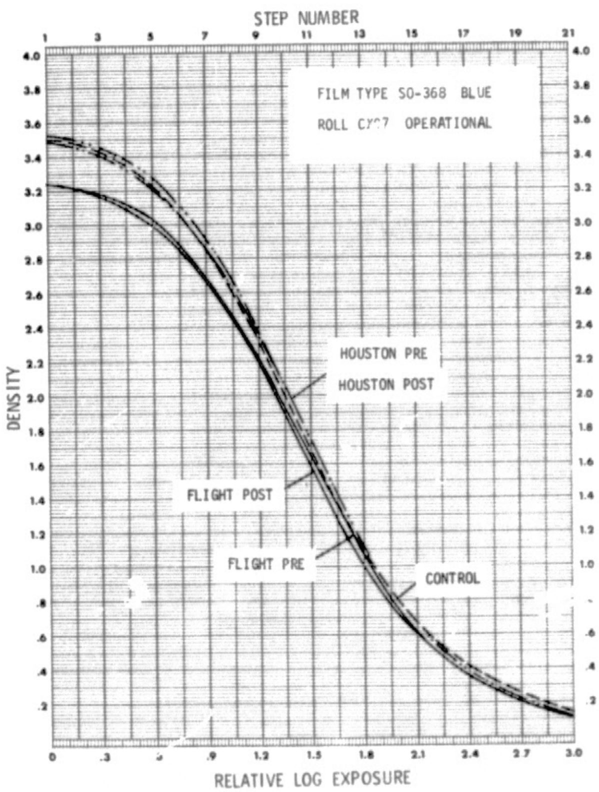
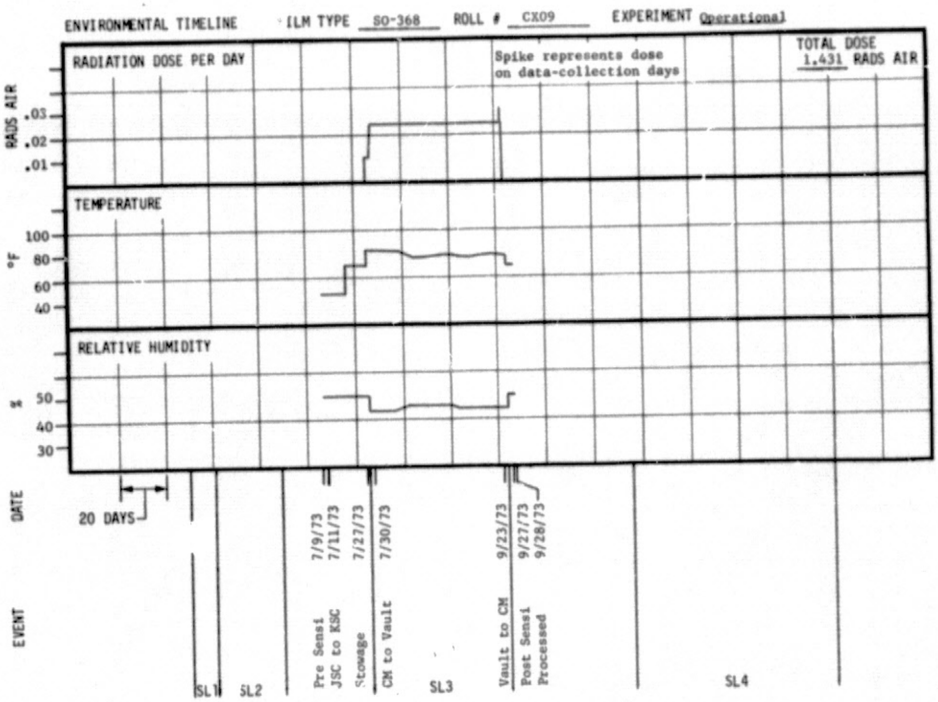


FIGURE D-96. FILM TYPE SO-368, ROLL CX07 (cont)



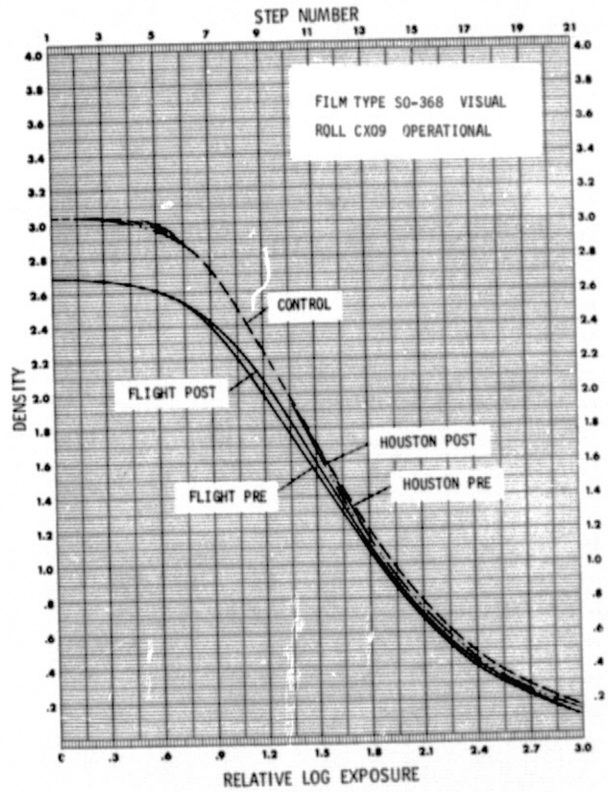
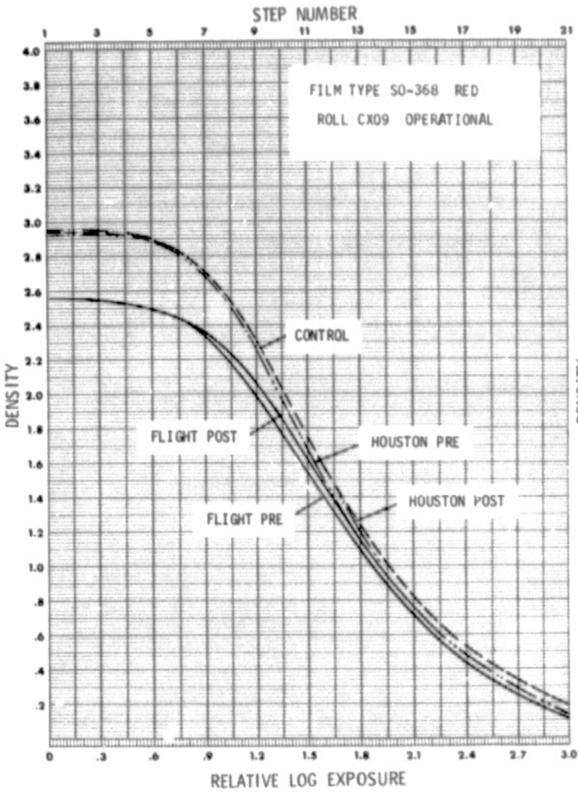
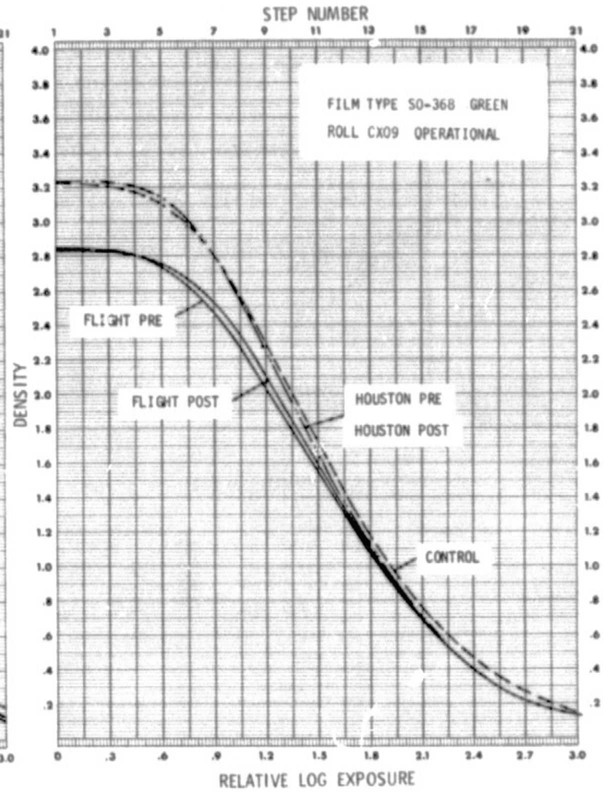


FIGURE D-97, FILM TYPE SO-368, ROLL CX09





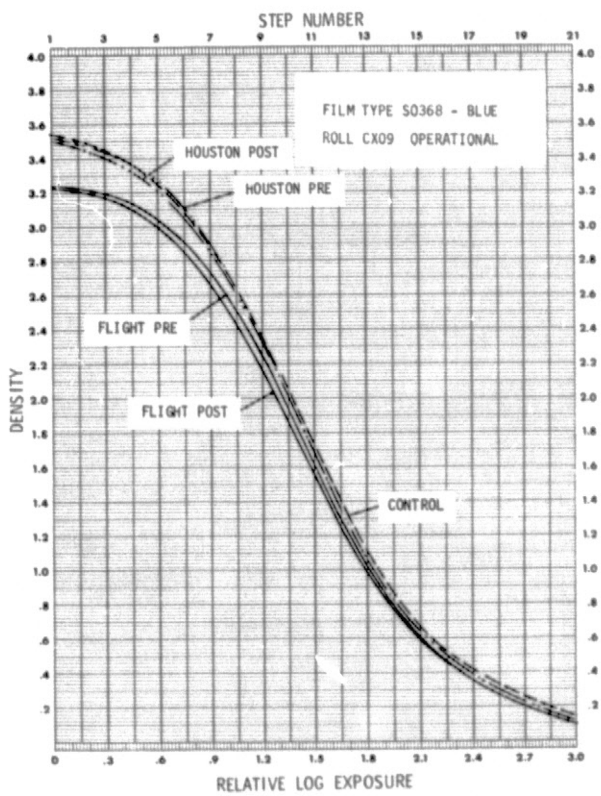
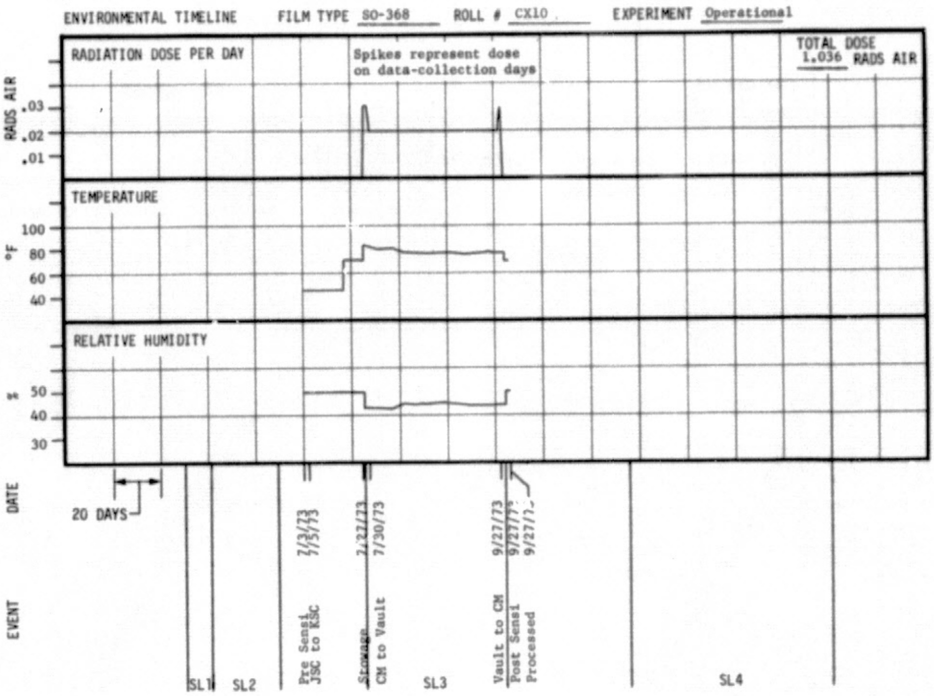


FIGURE D-97. FILM TYPE SO-368, ROLL CX09 (cont)



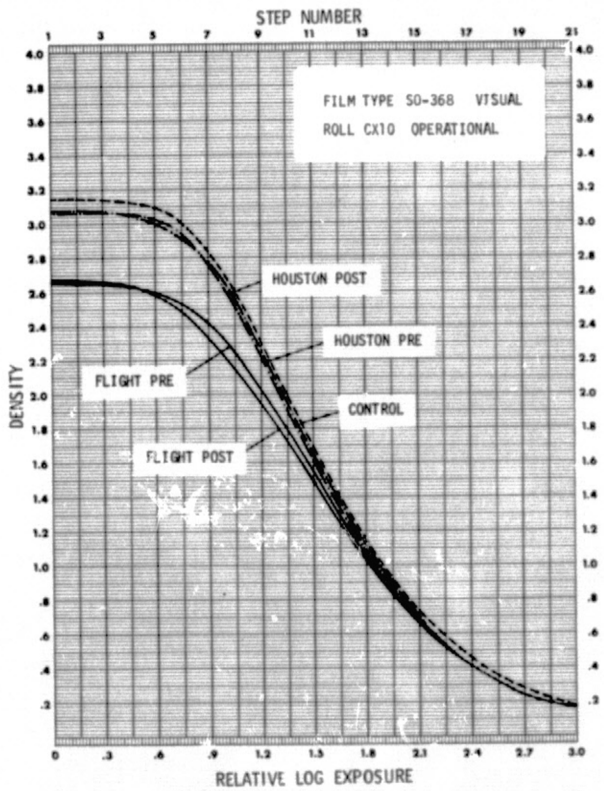
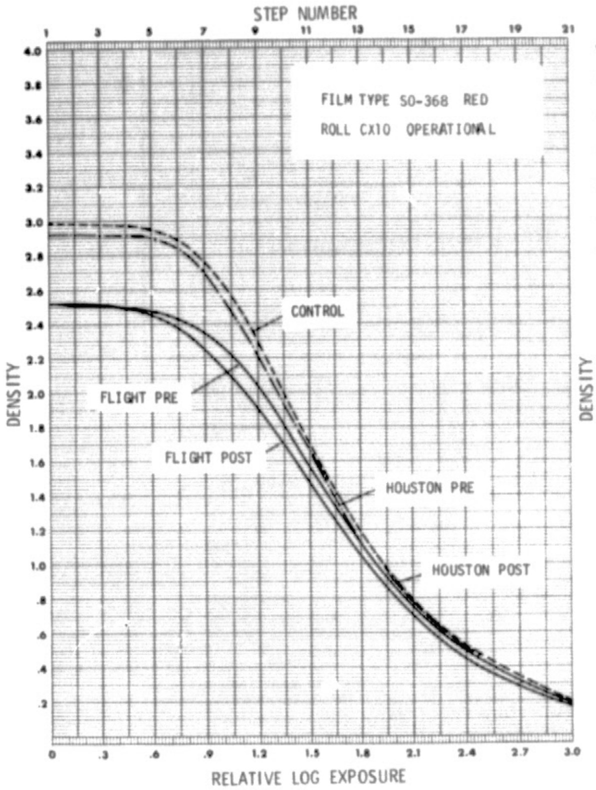
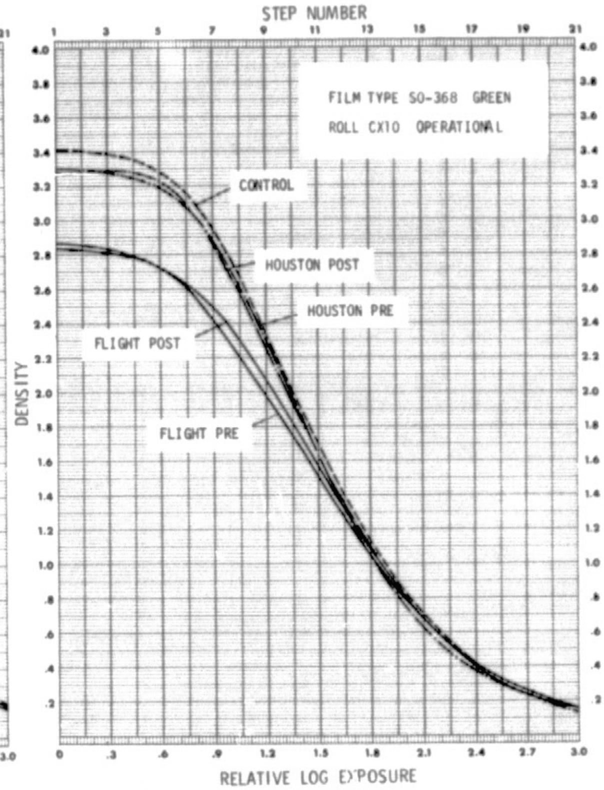


FIGURE D-98, FILM TYPE SO-368, ROLL CX10





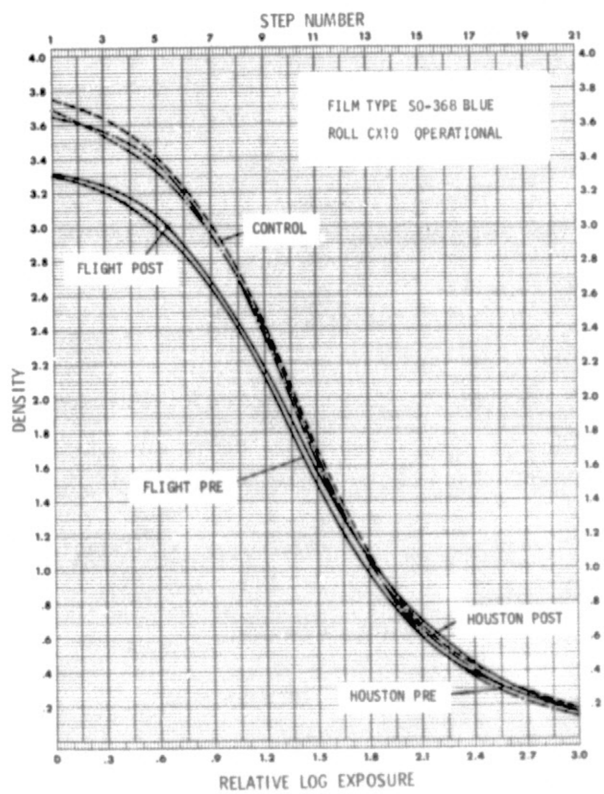
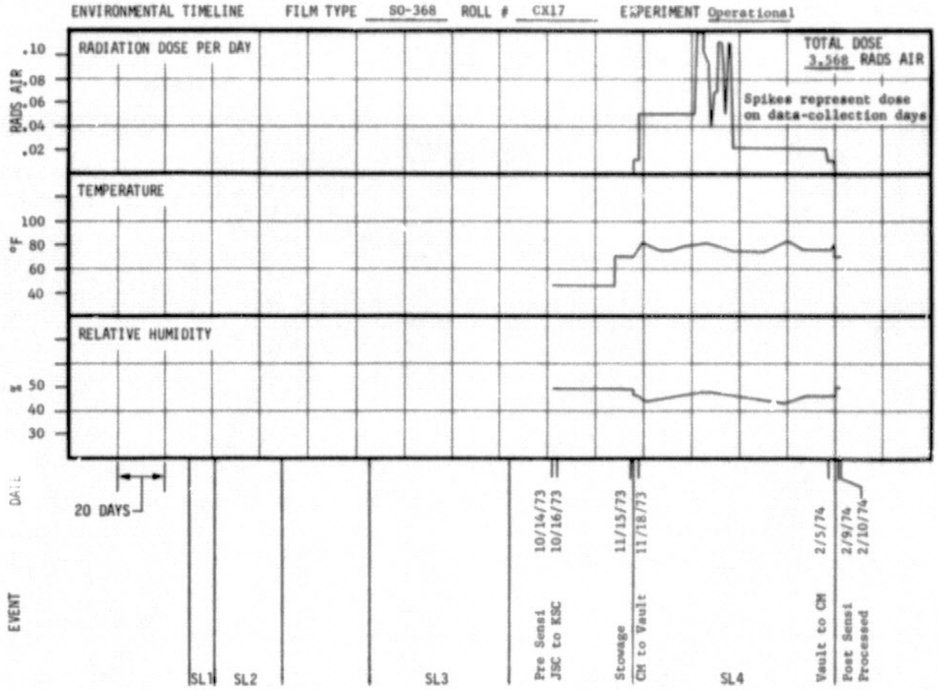


FIGURE D-98. FILM TYPE SO-368, ROLL CX10 (cont)



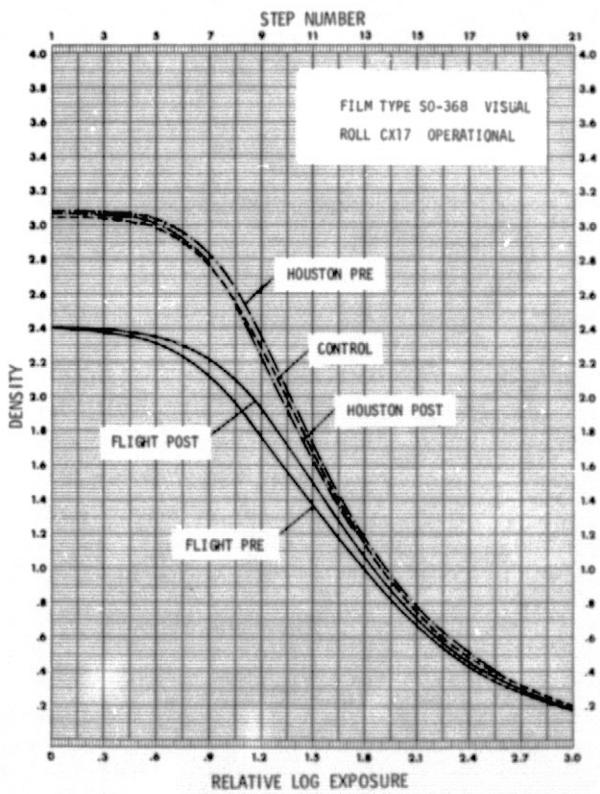
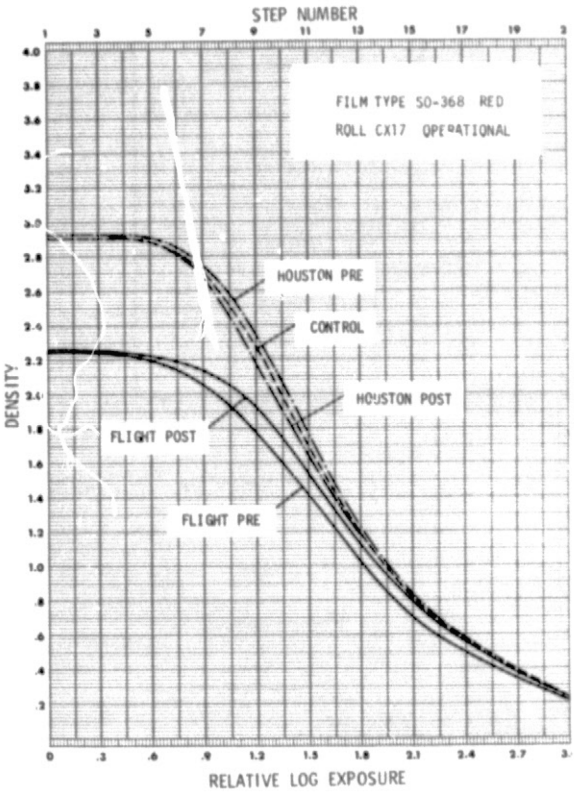
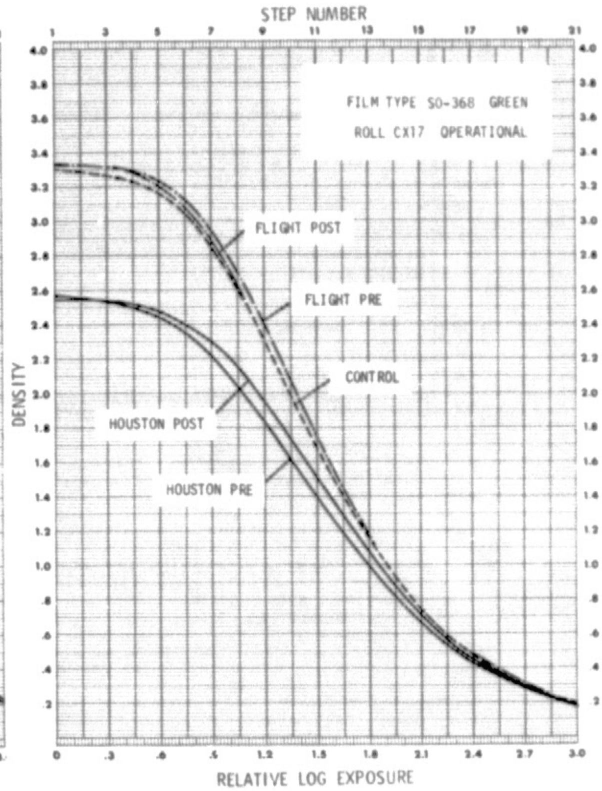


FIGURE D-99, FILM TYPE SO-368, ROLL CX17





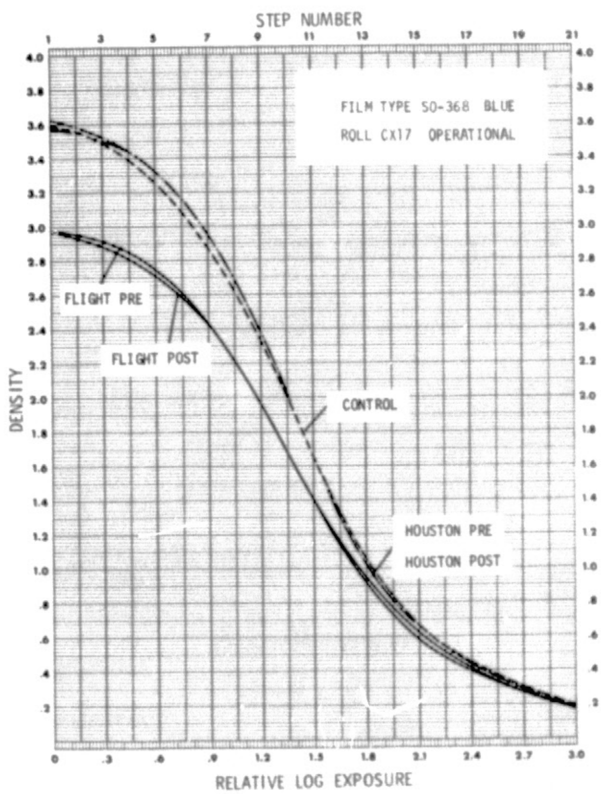
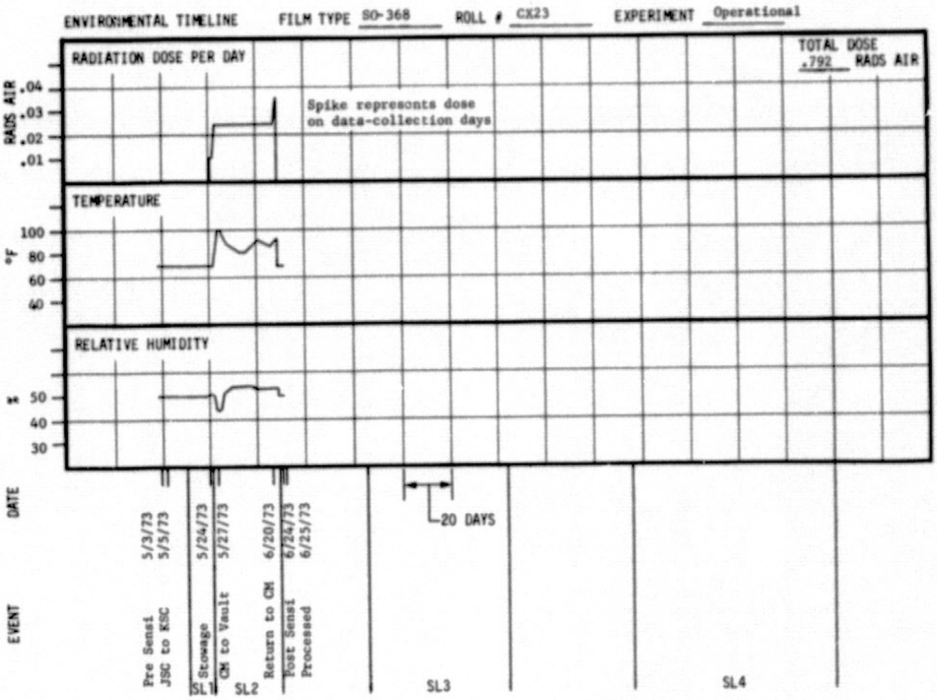


FIGURE D-99, FILM TYPE SO-368, ROLL CX17 (cont)



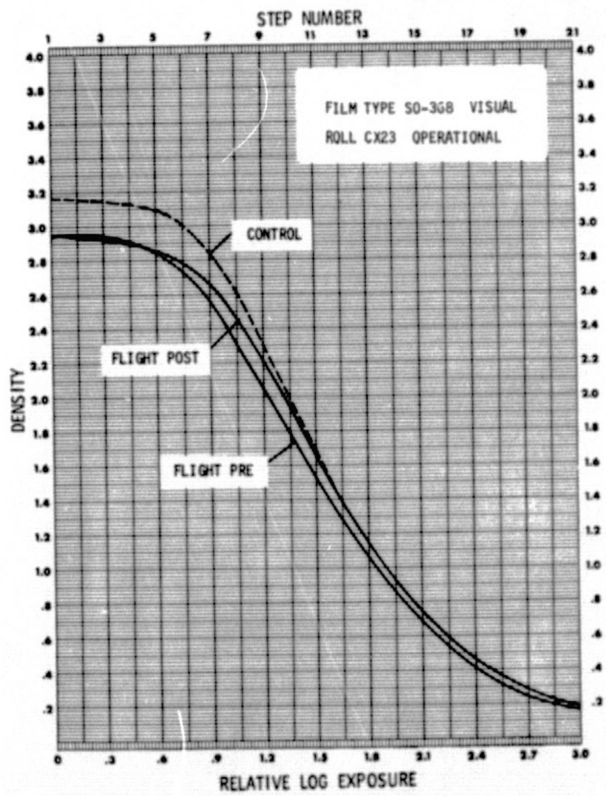
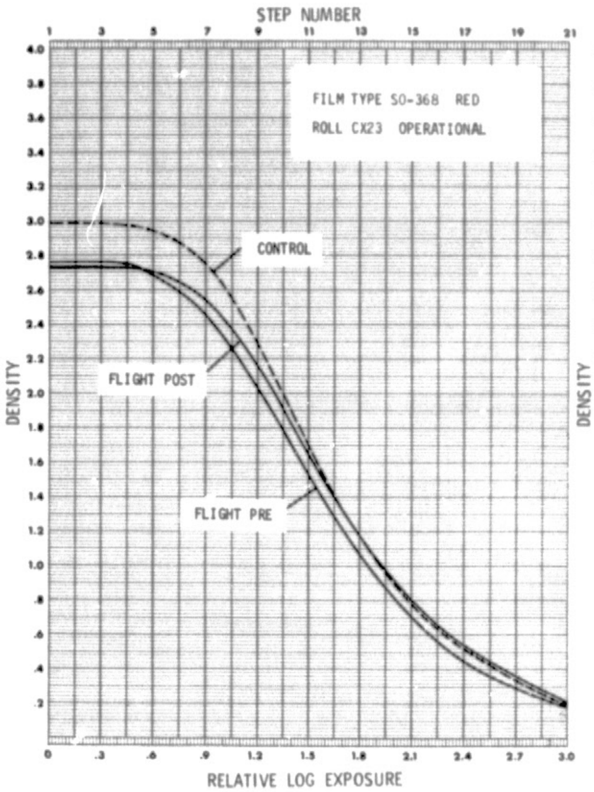
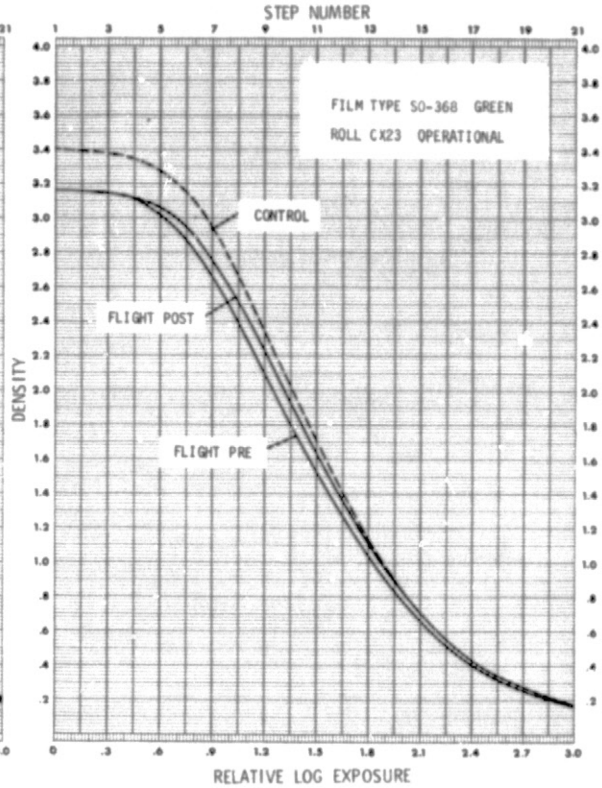


FIGURE D-100, FILM TYPE SO-368, ROLL CX23





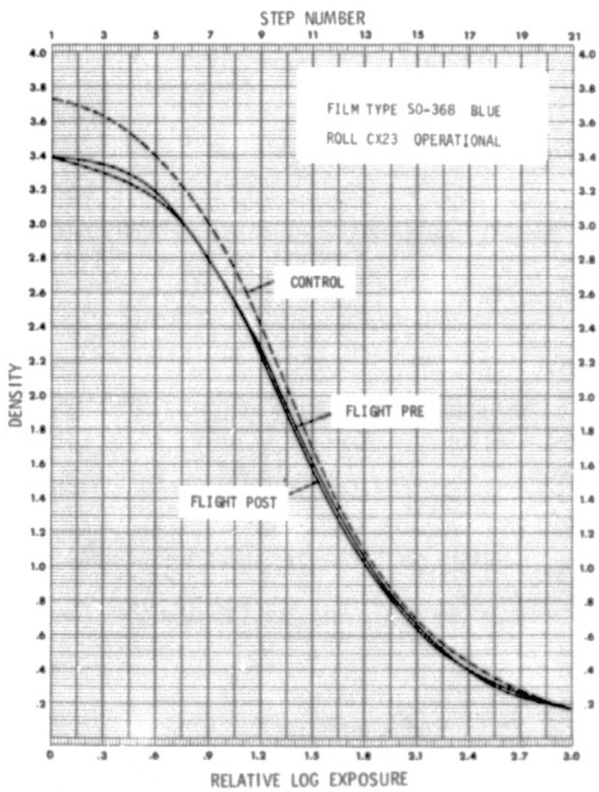
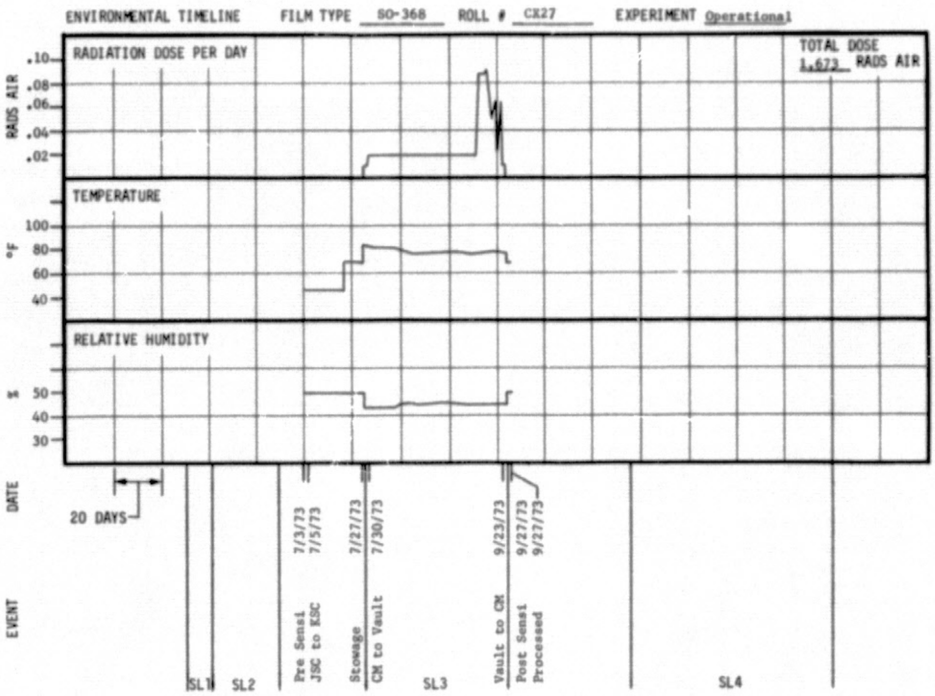


FIGURE D-100, FILM TYPE SO-368, ROLL CX23 (cont)



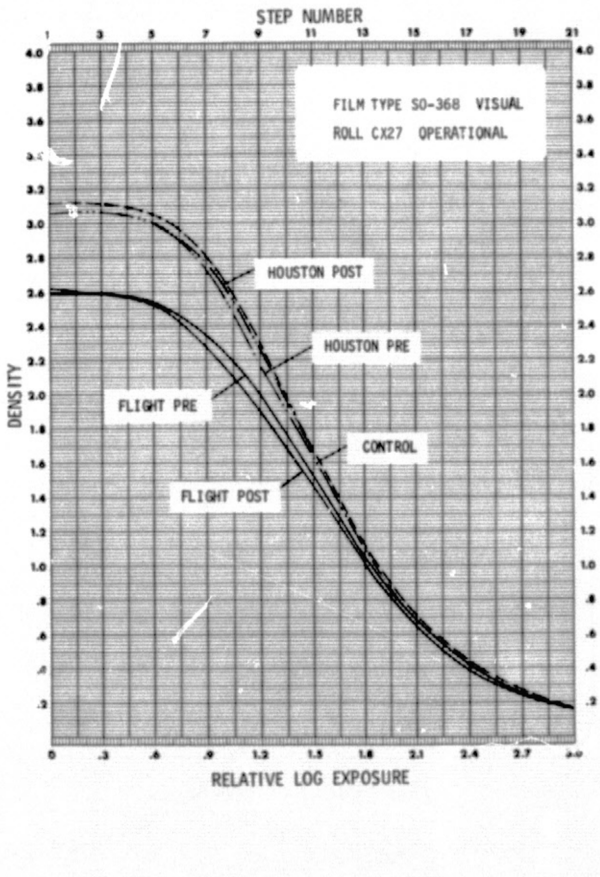


FIGURE D-101, FILM TYPE SO-368, ROLL CX27

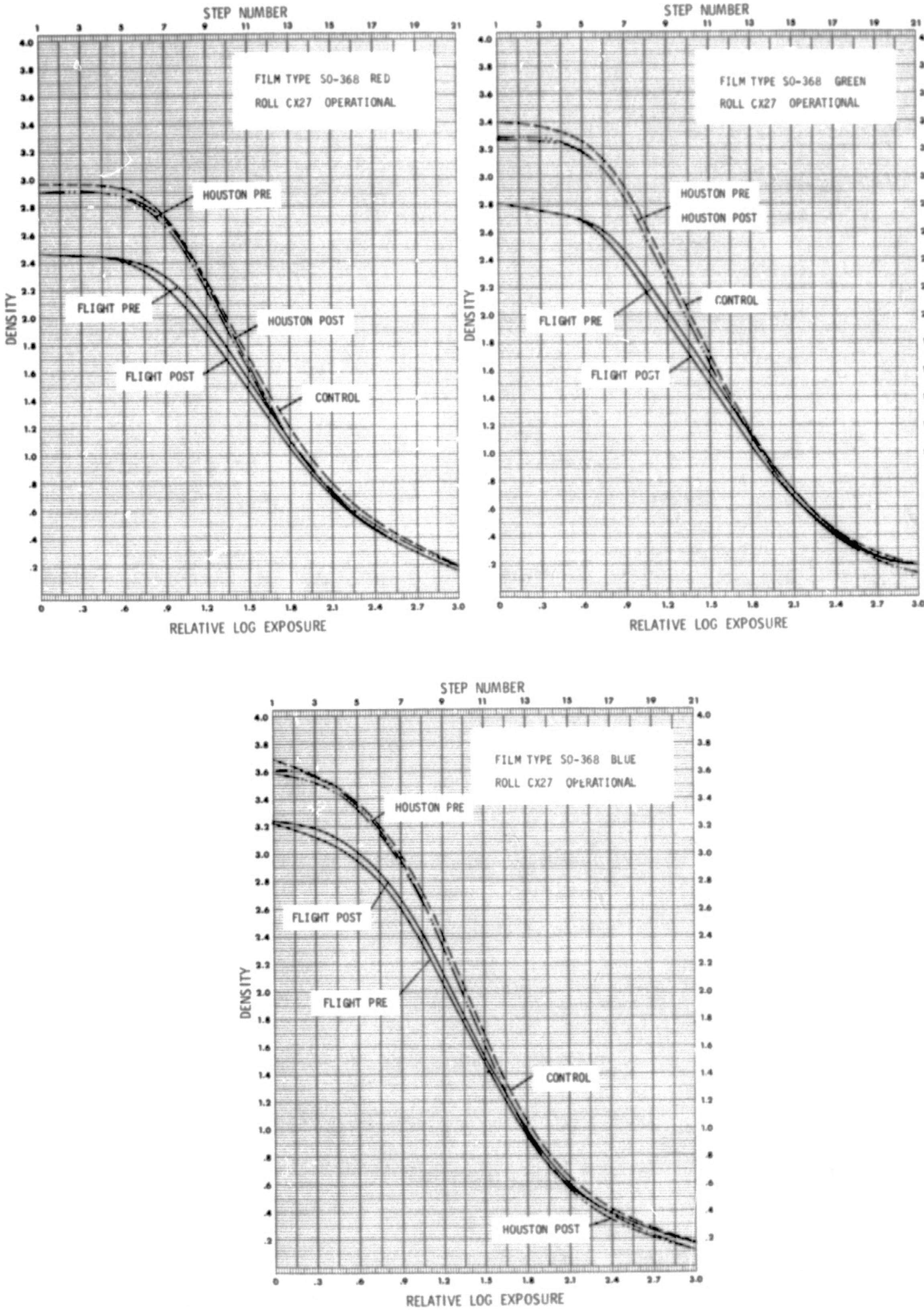
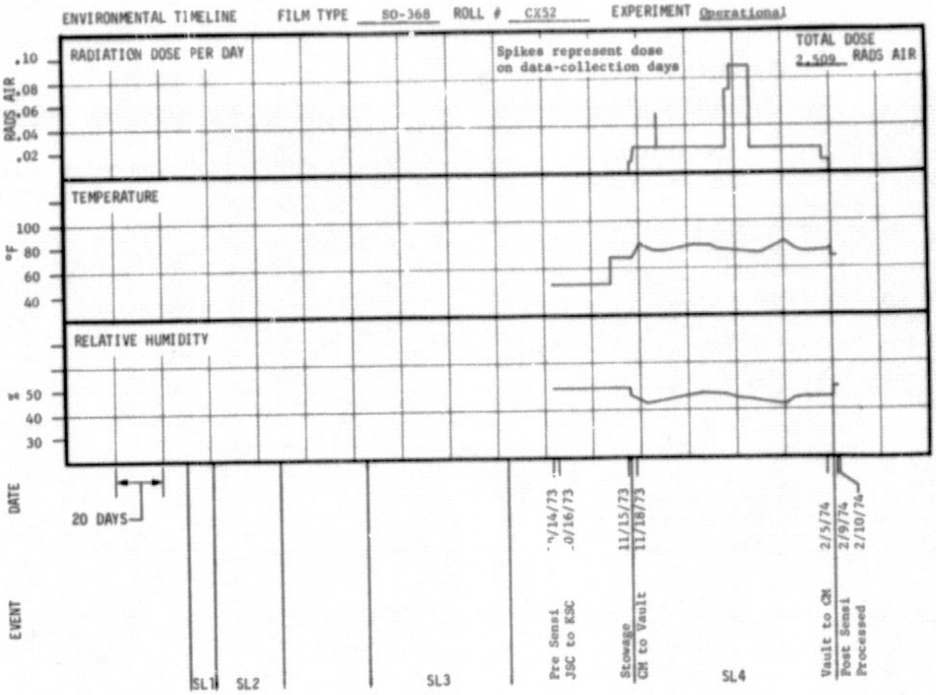


FIGURE D-101. FILM TYPE SO-368, ROLL CX27 (cont)



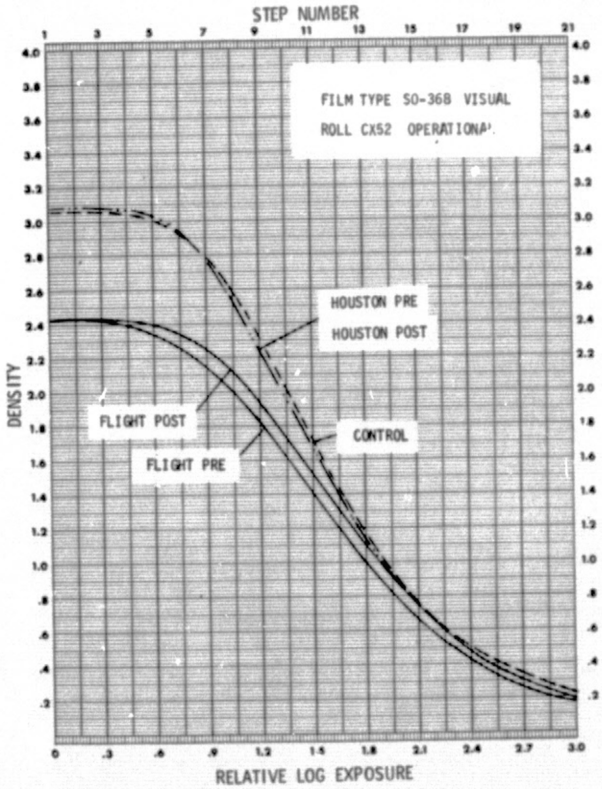
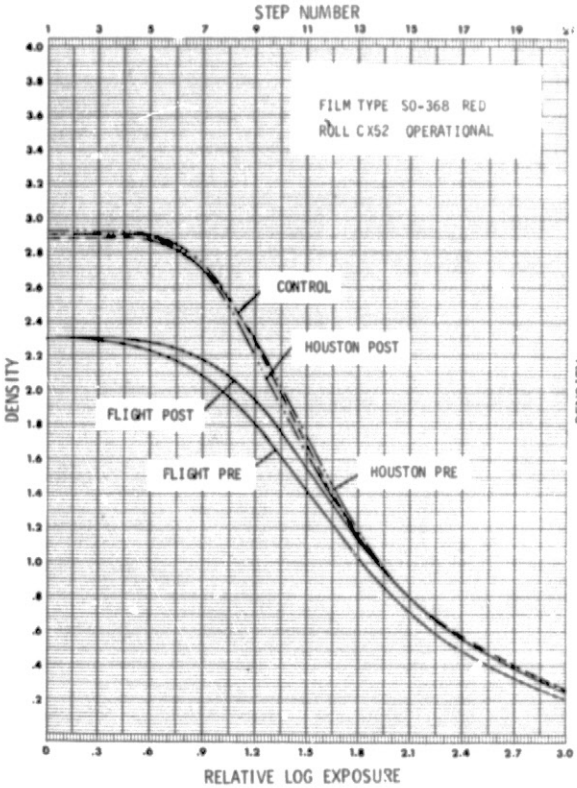
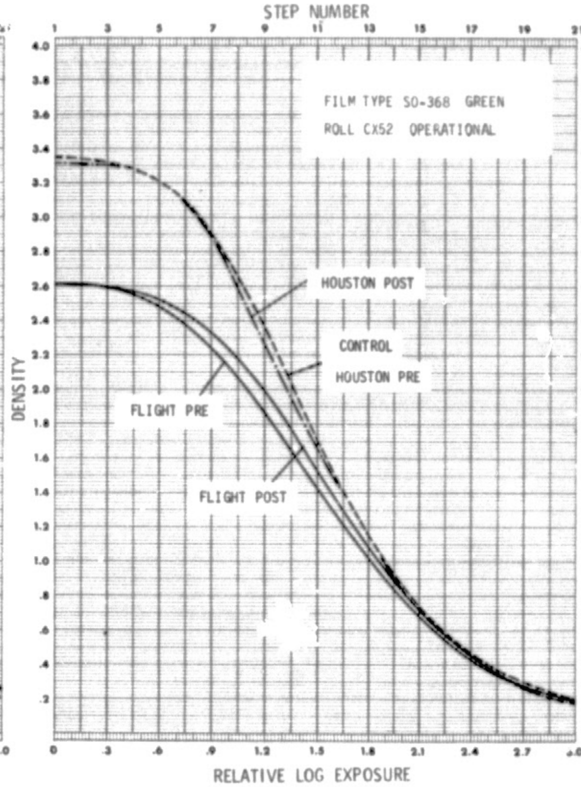


FIGURE D-102, FILM TYPE SO-368, ROLL CX52





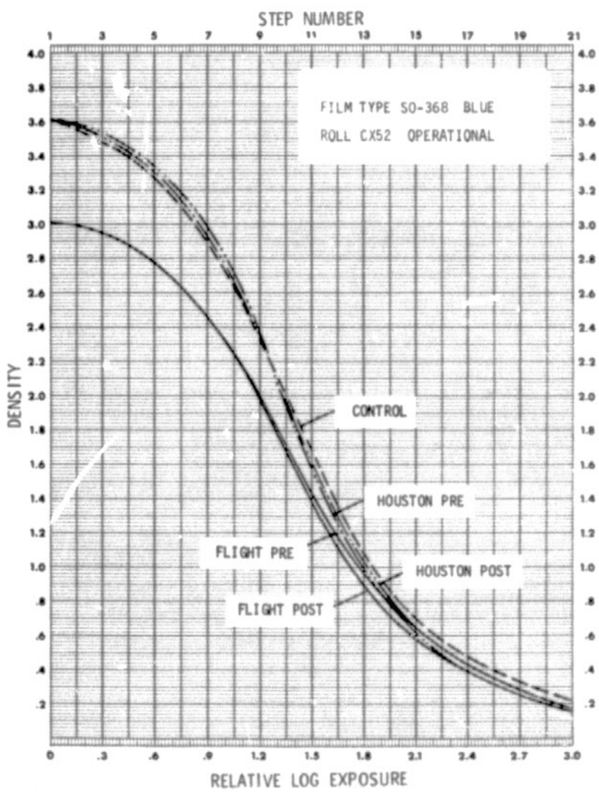
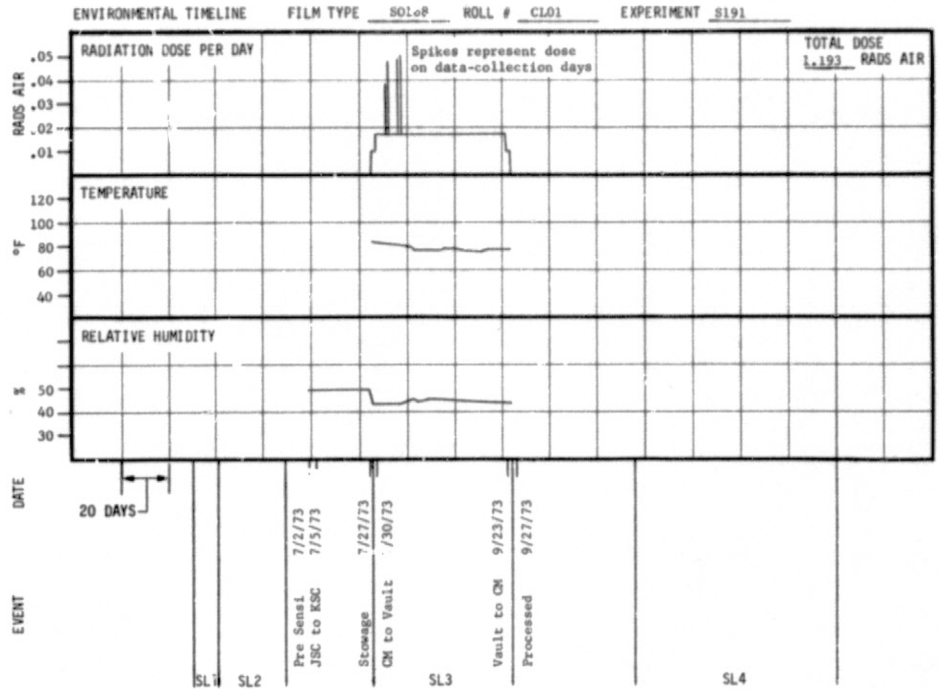


FIGURE D-102, FILM TYPE SO-368, ROLL CX52 (cont)



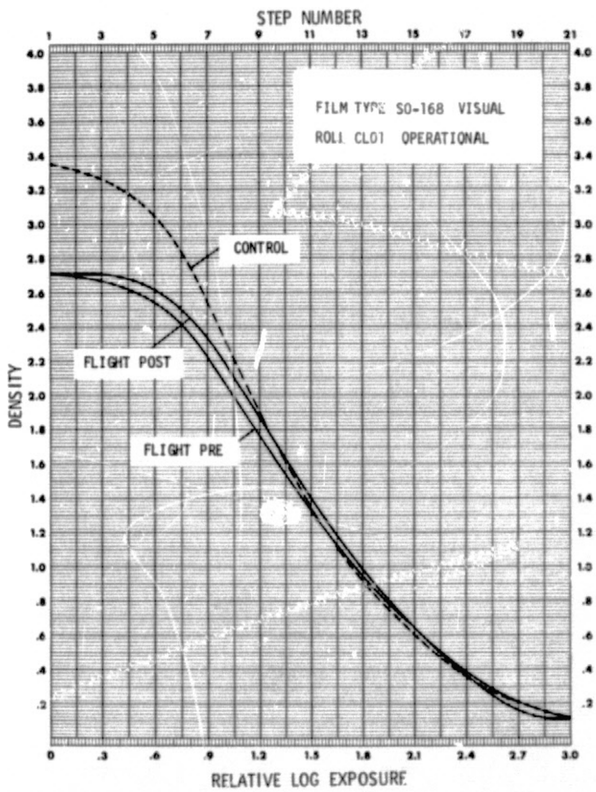
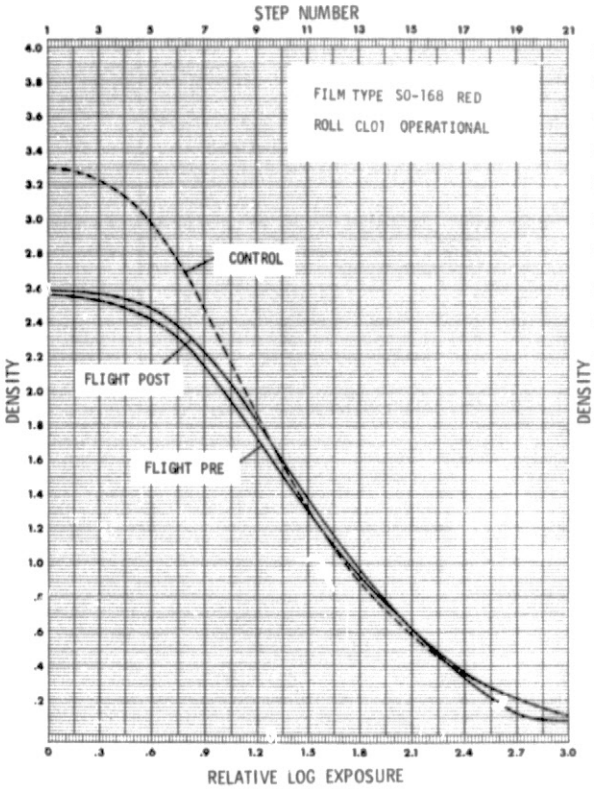
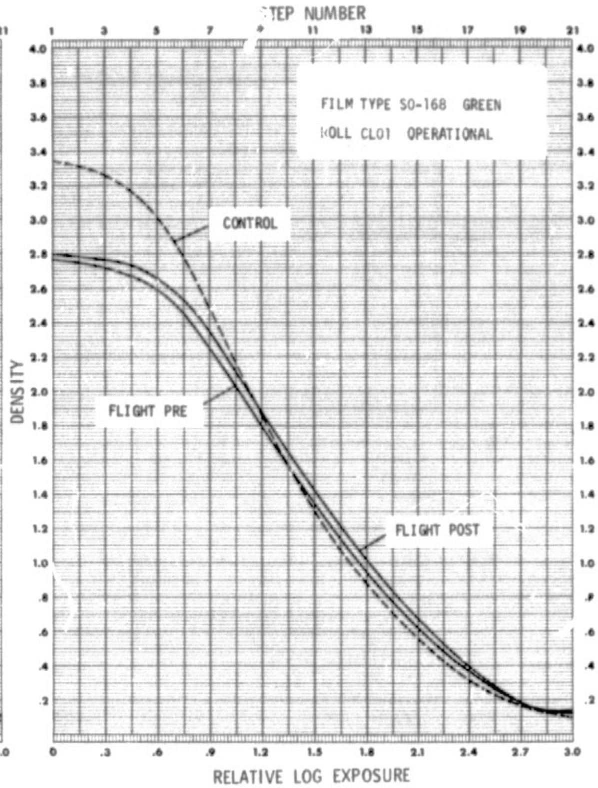


FIGURE D-103, FILM TYPE SO-168, ROLL CL01





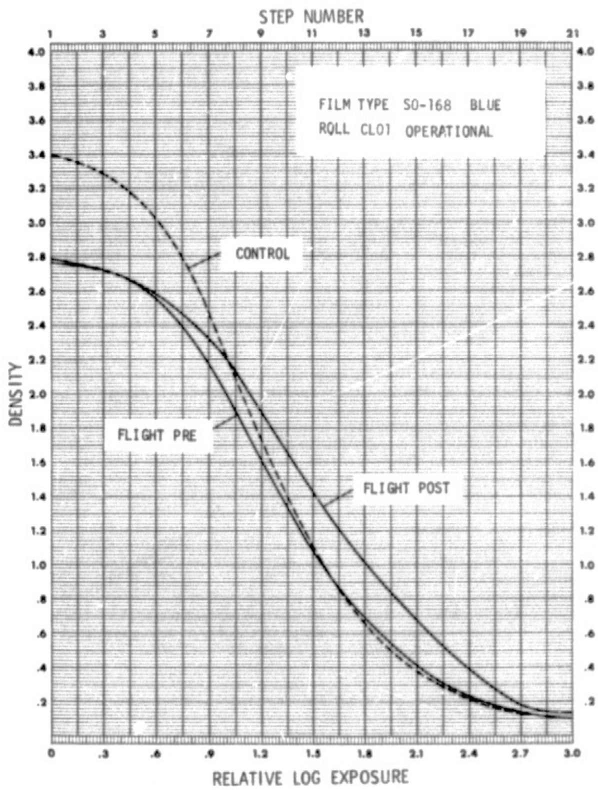
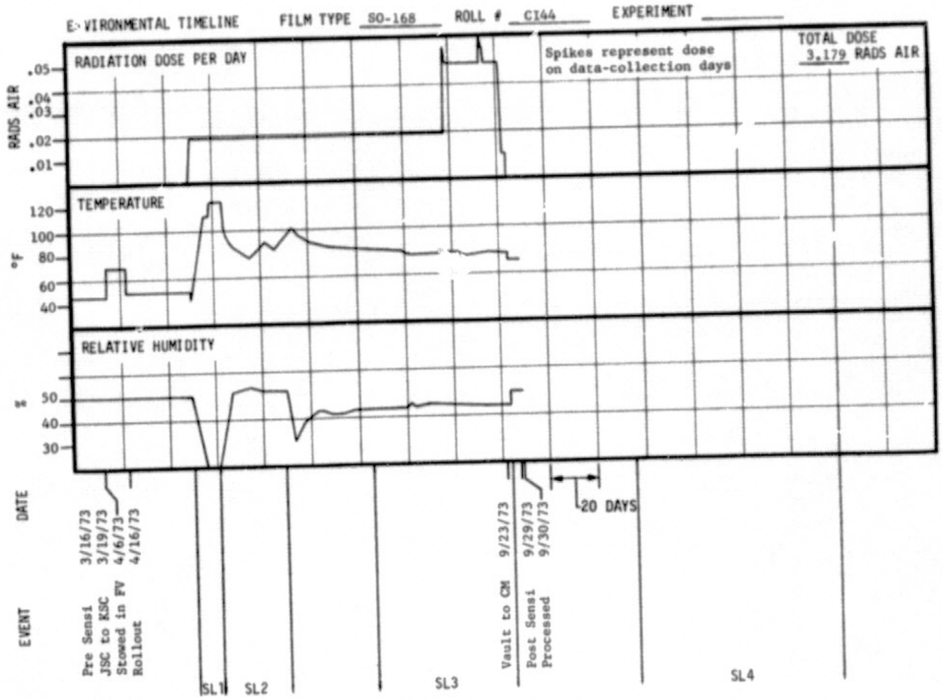


FIGURE D-103, FILM TYPE SO-168, ROLL CL01 (cont)



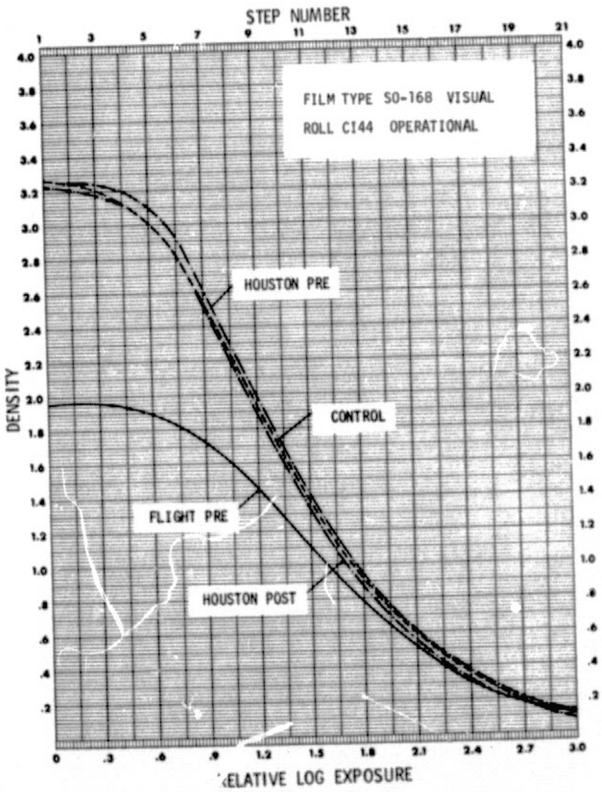
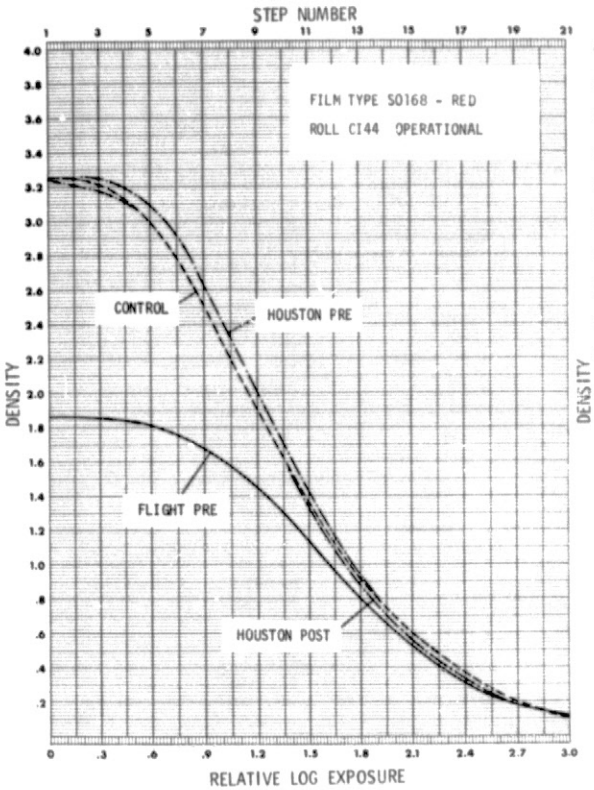
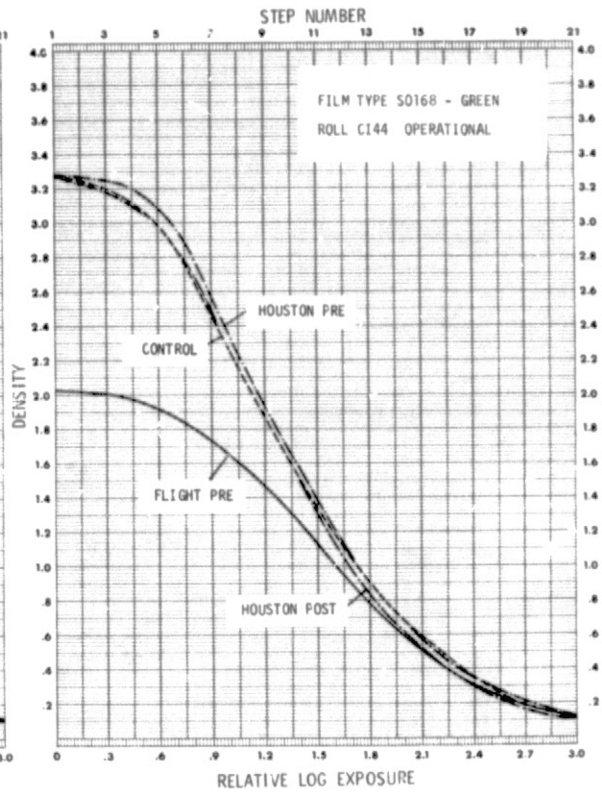


FIGURE D-104, FILM TYPE SO-168, ROLL C144





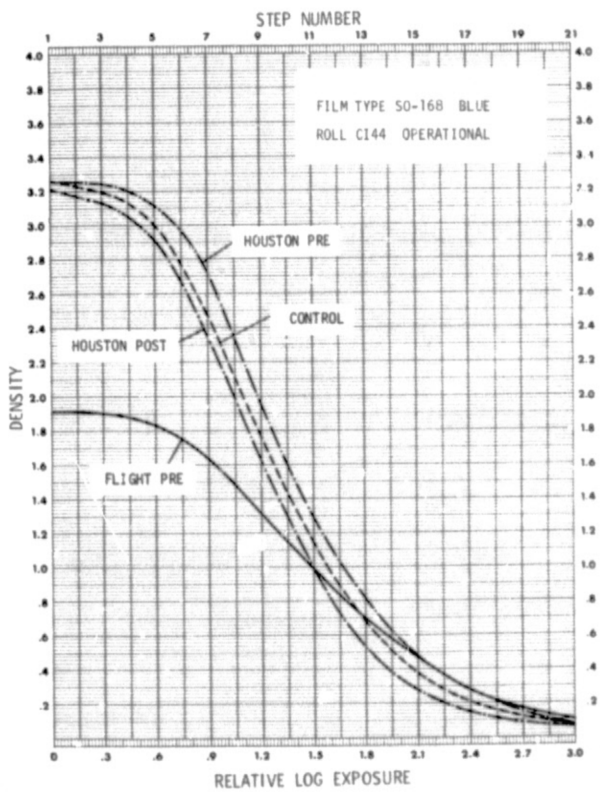
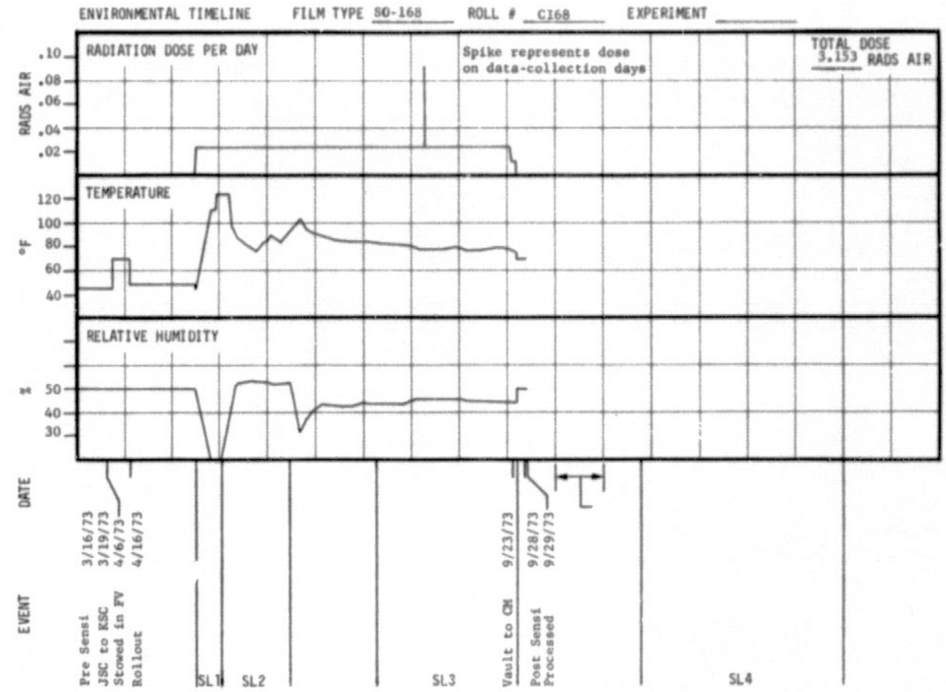


FIGURE D-104, FILM TYPE SO-168, ROLL C144 (cont)



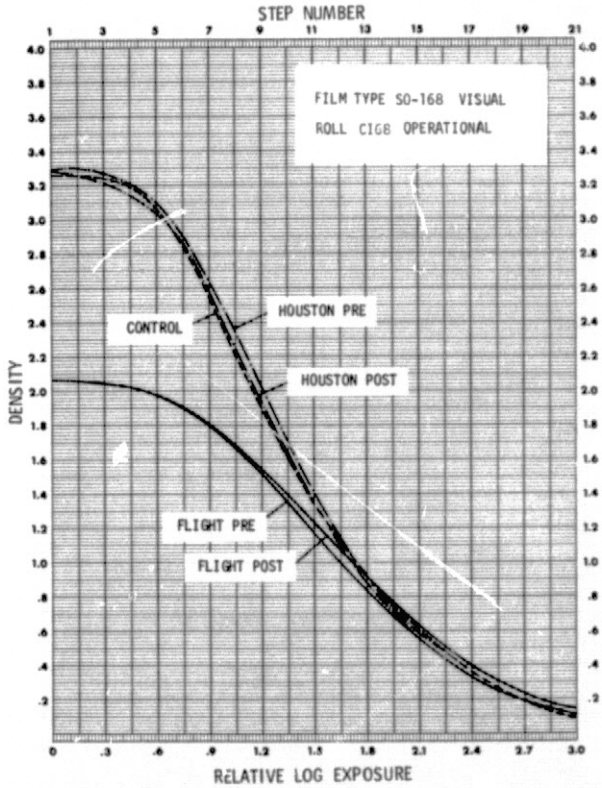


FIGURE D-105, FILM TYPE SO-168, ROLL C168

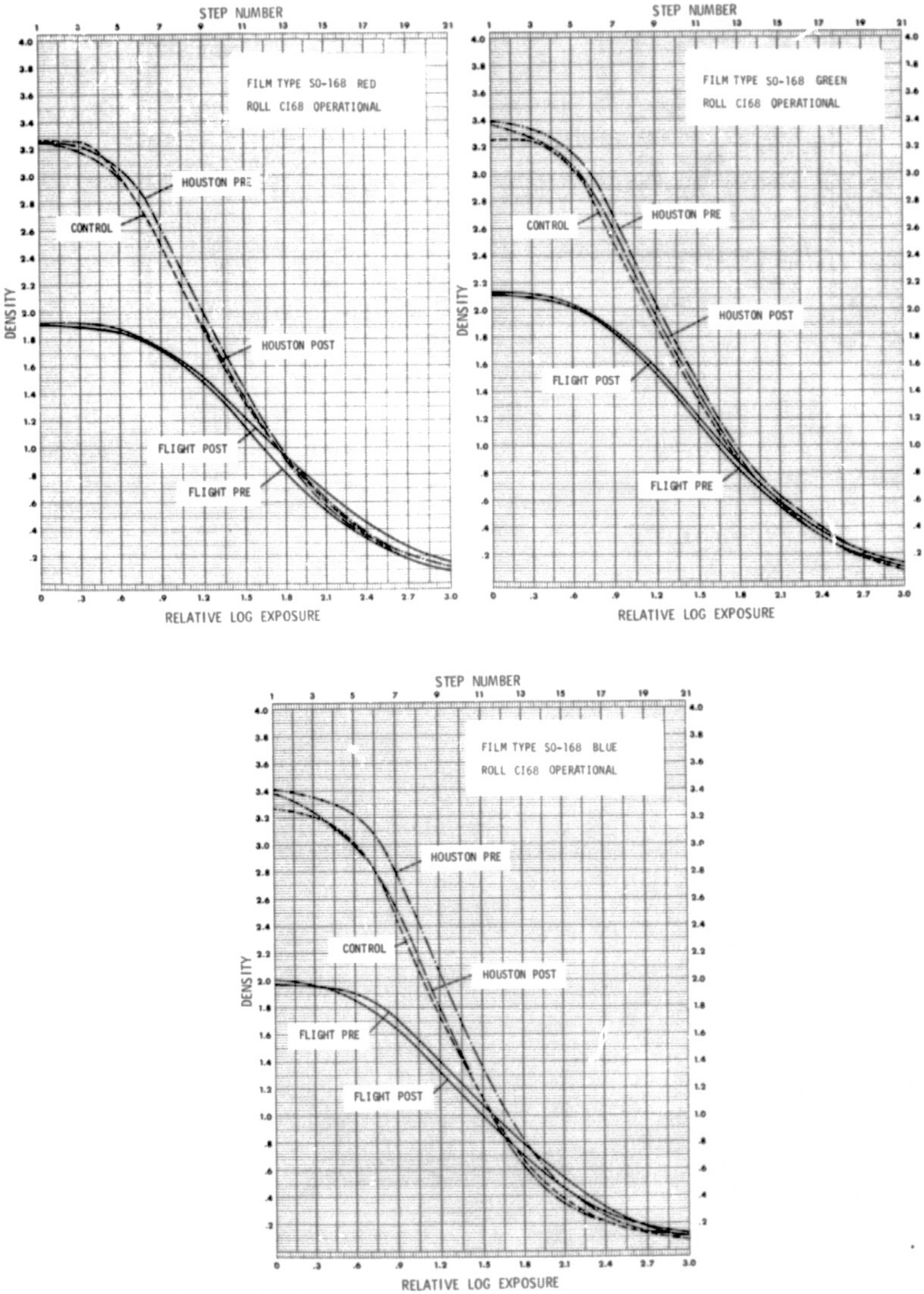
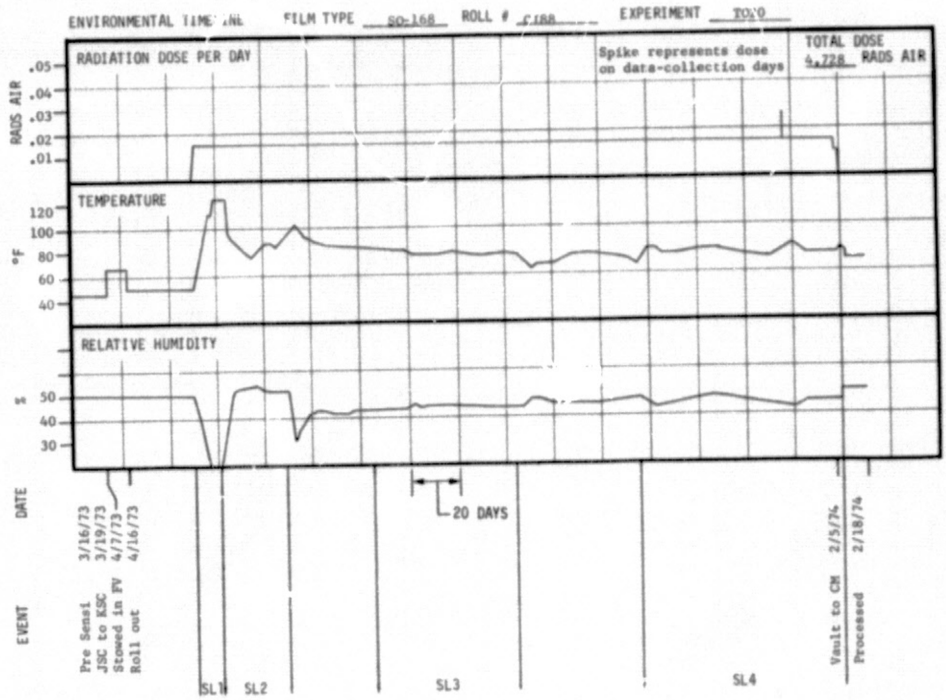


FIGURE D-105, FILM TYPE SO-168, ROLL C168 (cont)



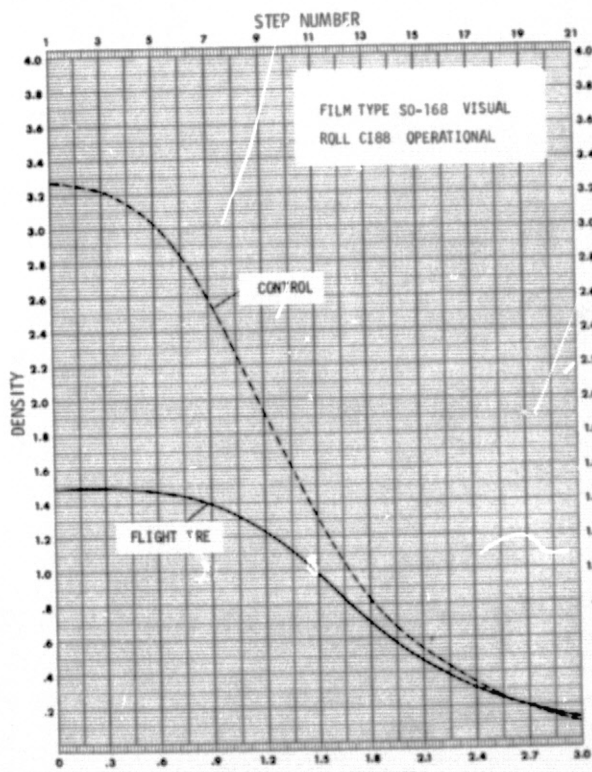
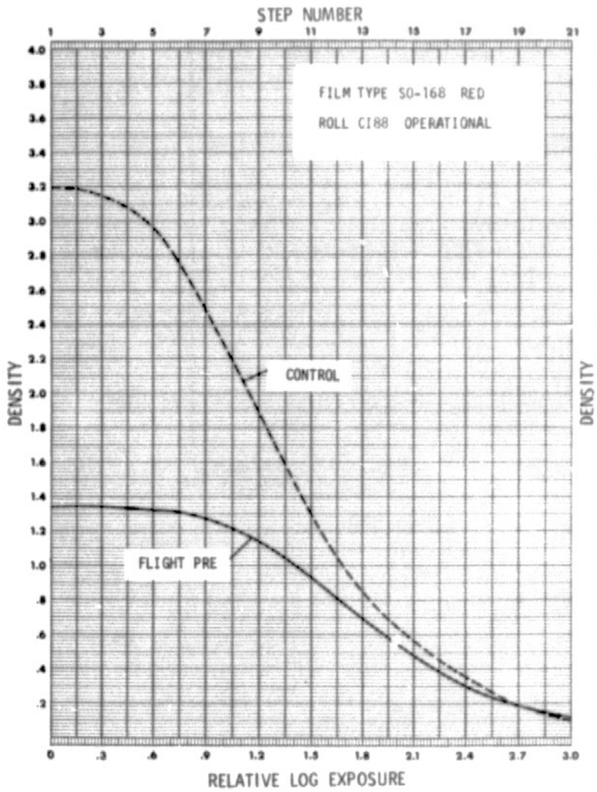
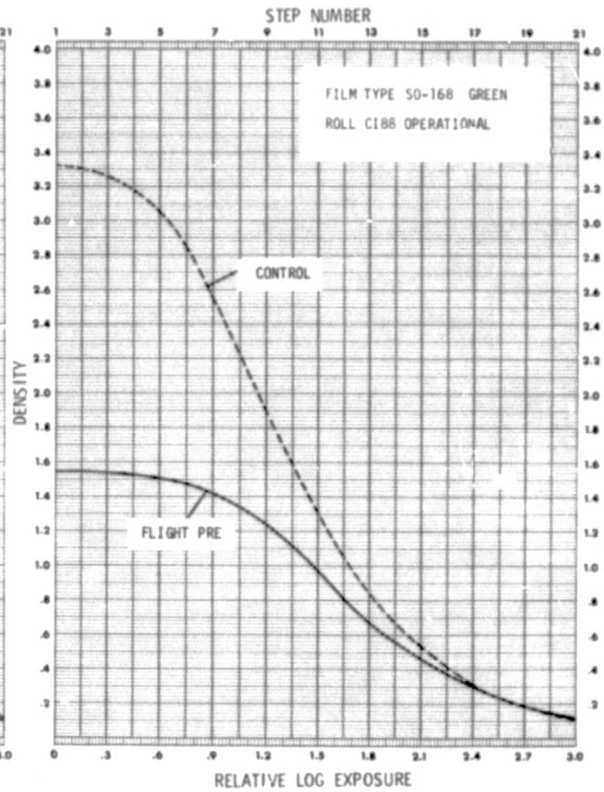


FIGURE D-106, FILM TYPE SO-168, ROLL C188





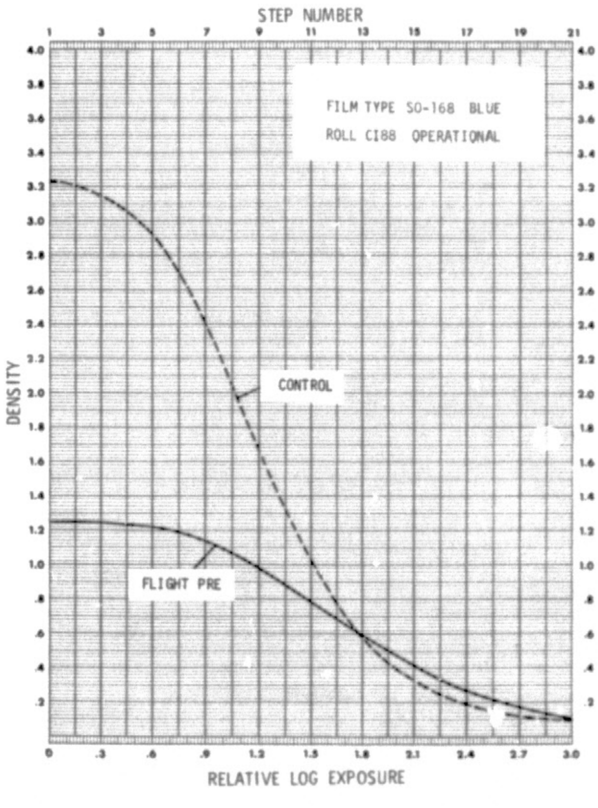
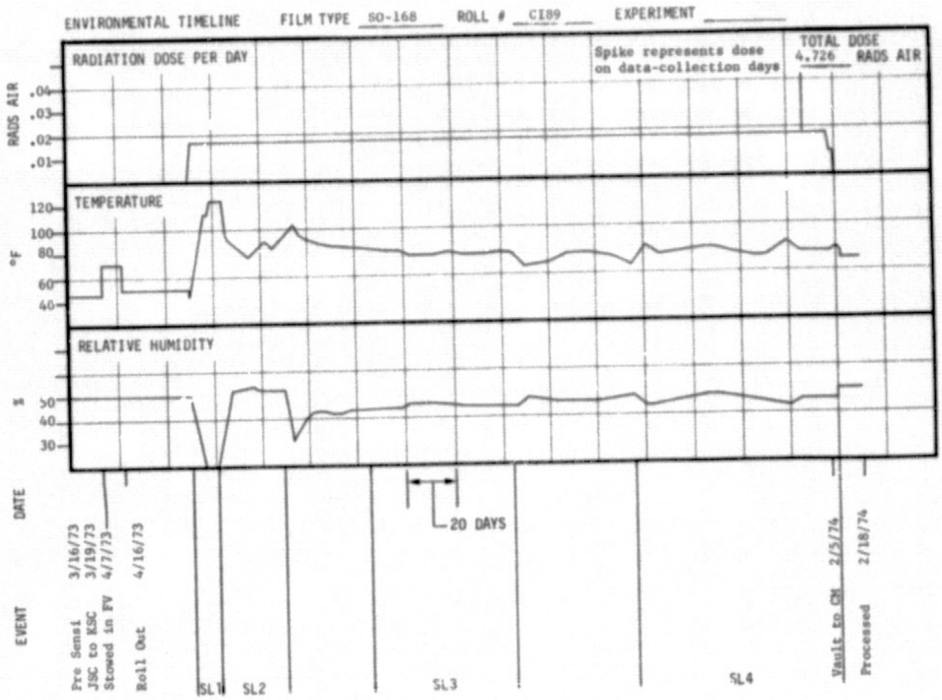


FIGURE D-106. FILM TYPE SO-168, ROLL C188 (cont)



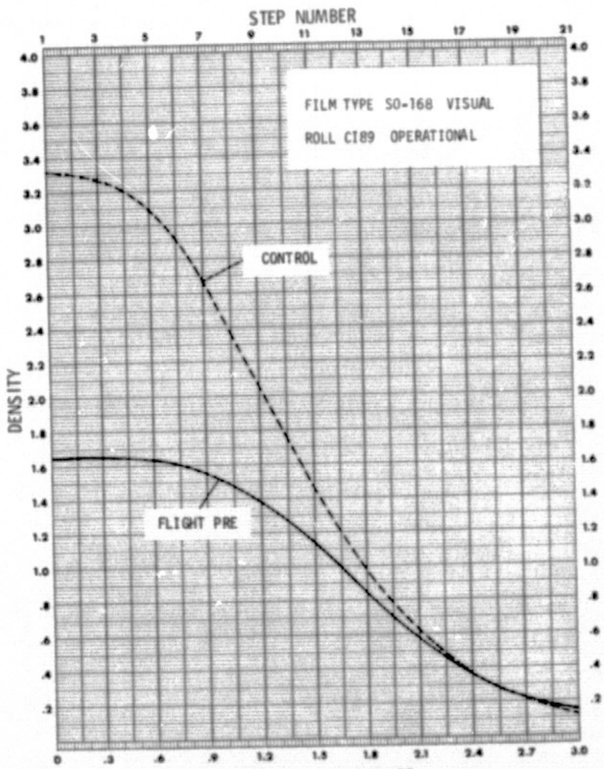
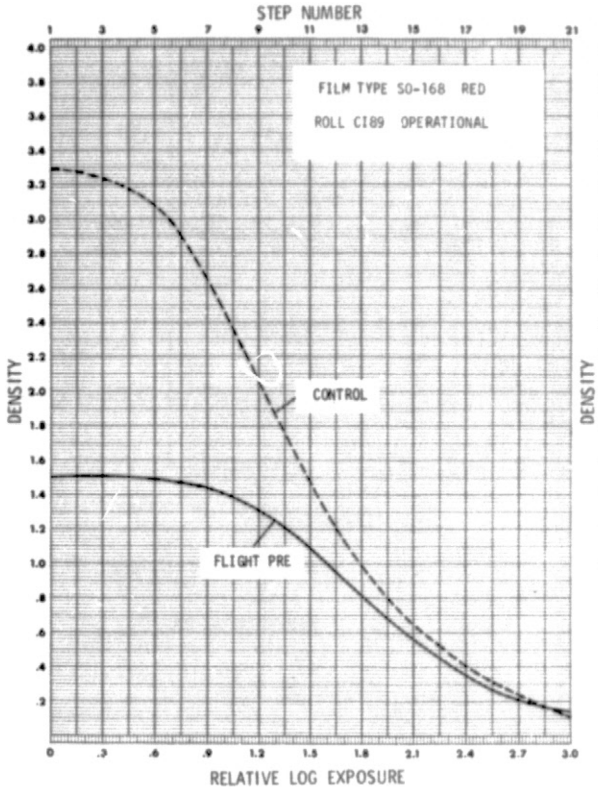
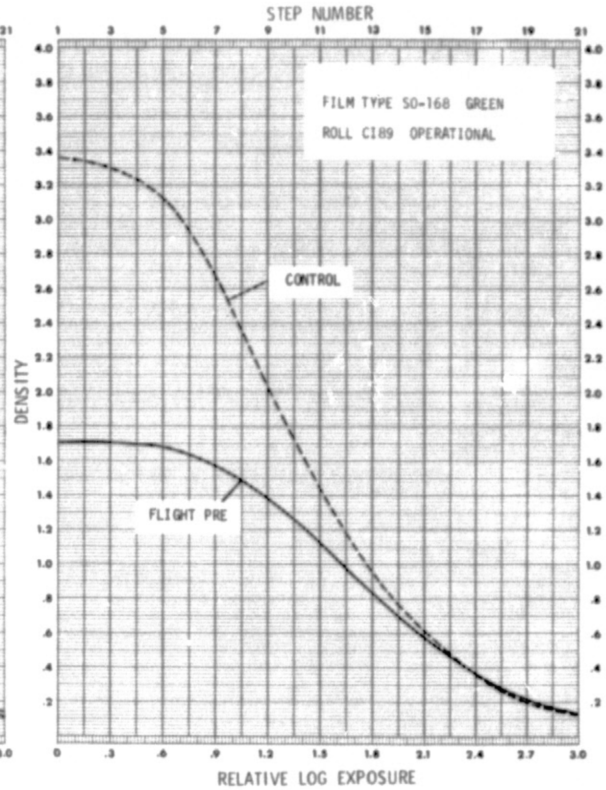


FIGURE D-107, FILM TYPE SO-168, ROLL C189





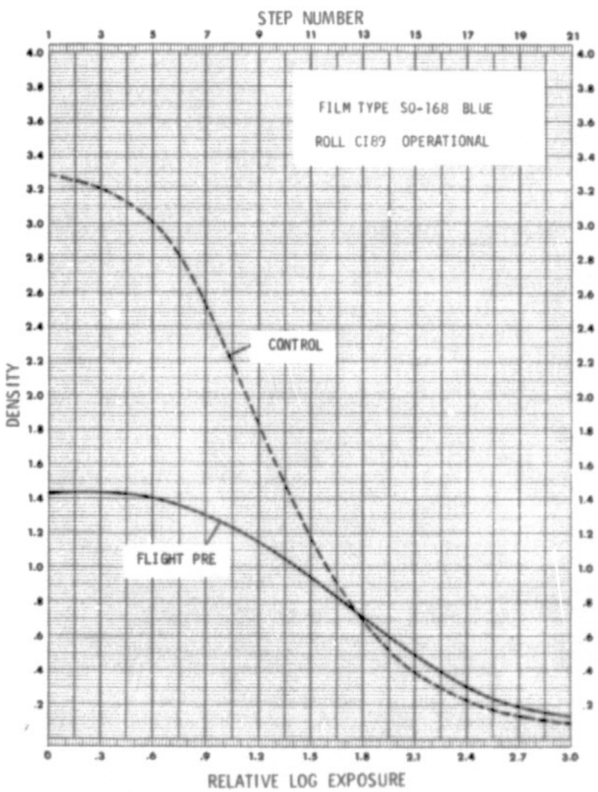
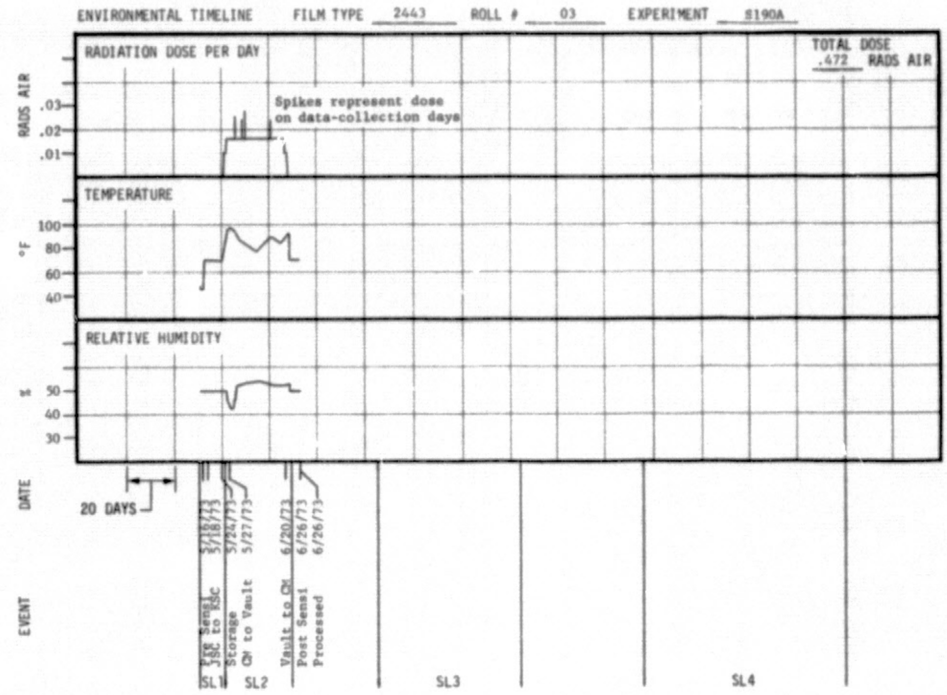


FIGURE D-107, FILM TYPE SO-168, ROLL C189 (cont)



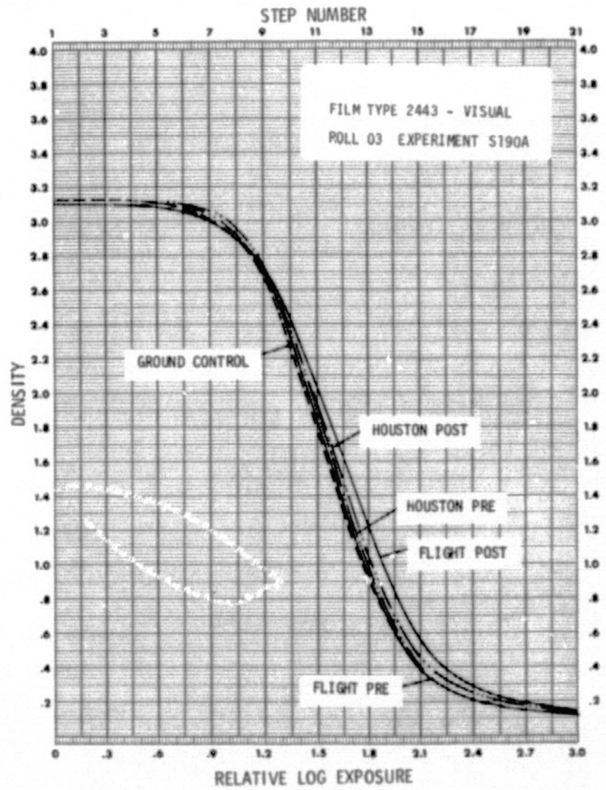
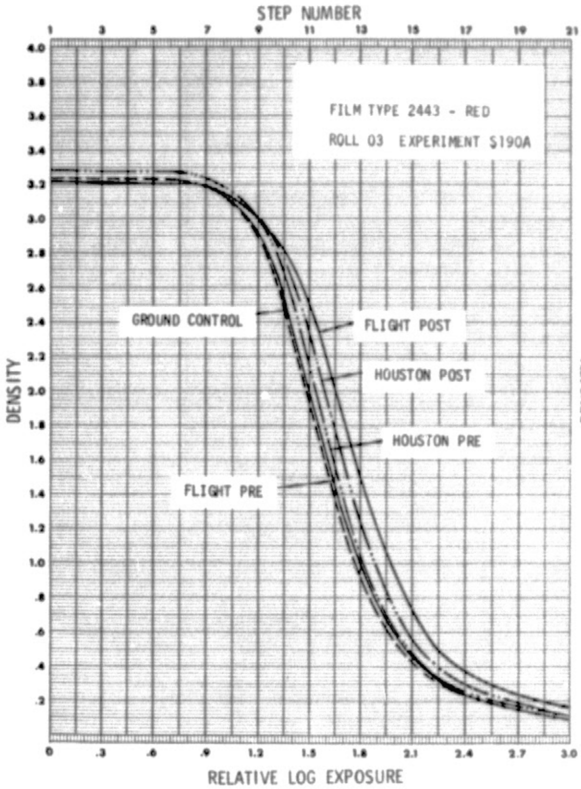
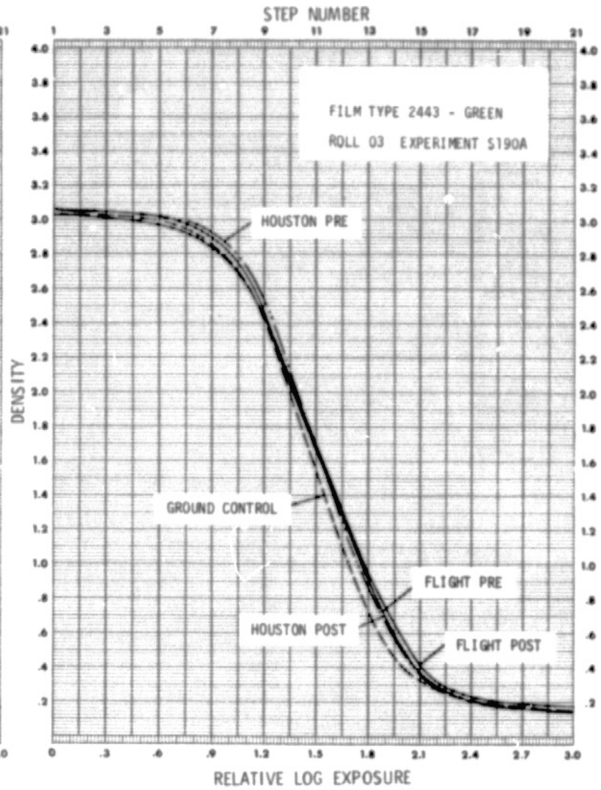


FIGURE D-108, FILM TYPE 2443, ROLL 03





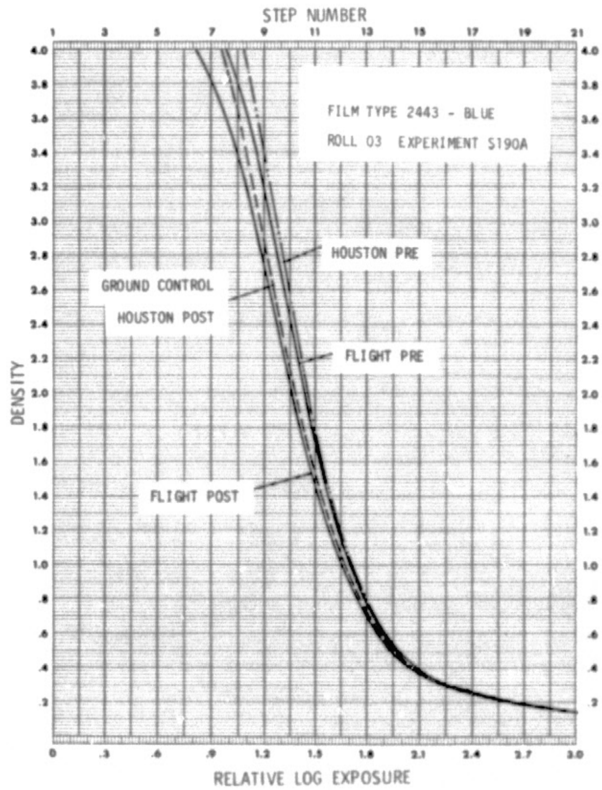
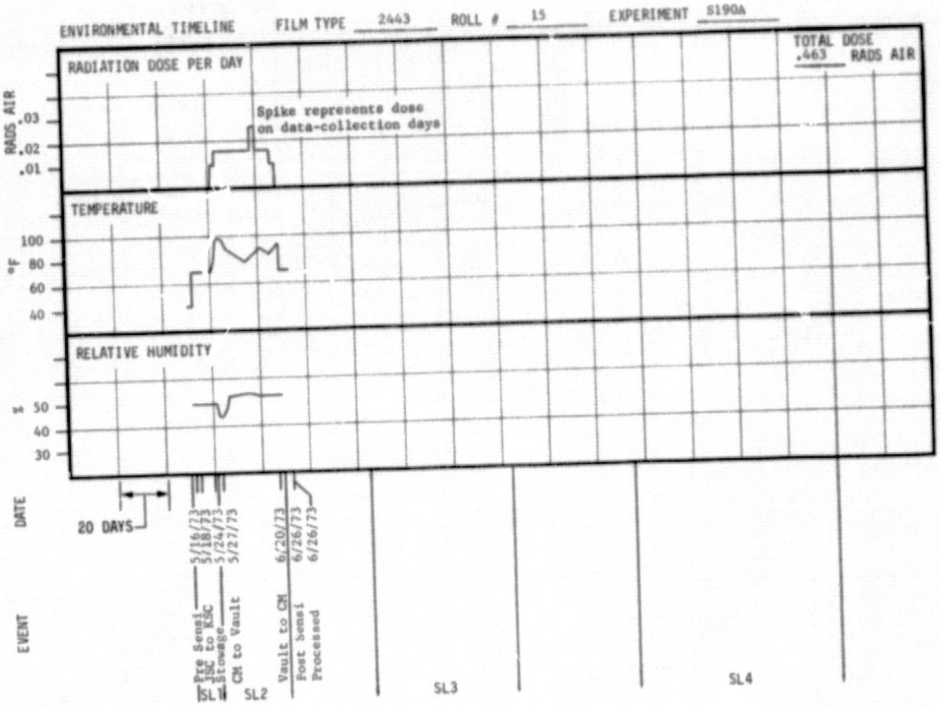


FIGURE D-108. FILM TYPE 2443, ROLL 03 (cont)



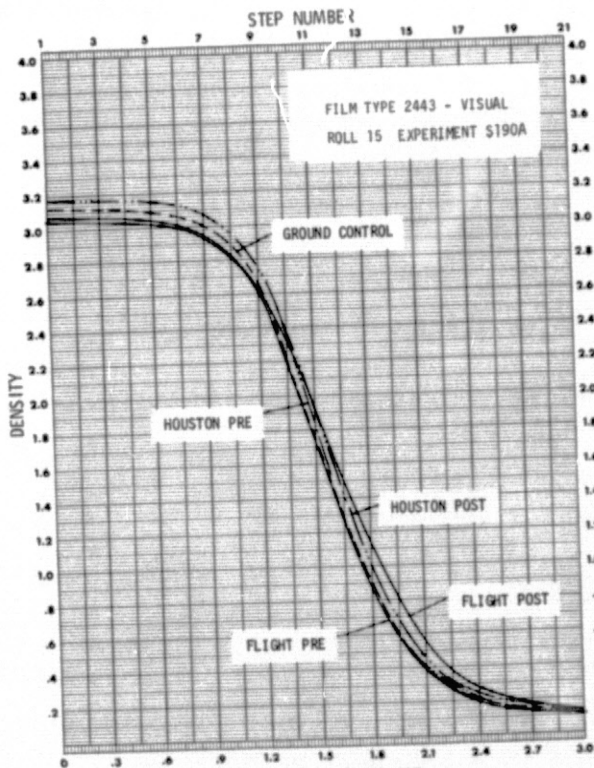
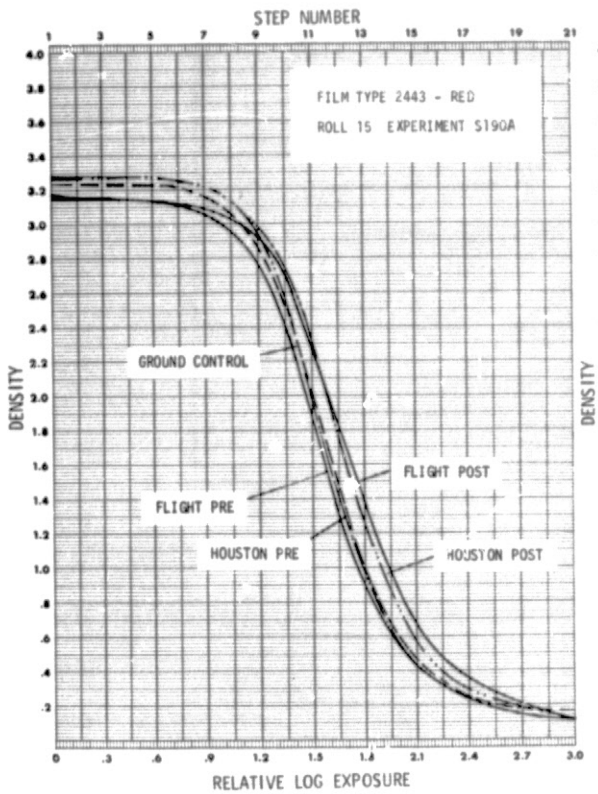
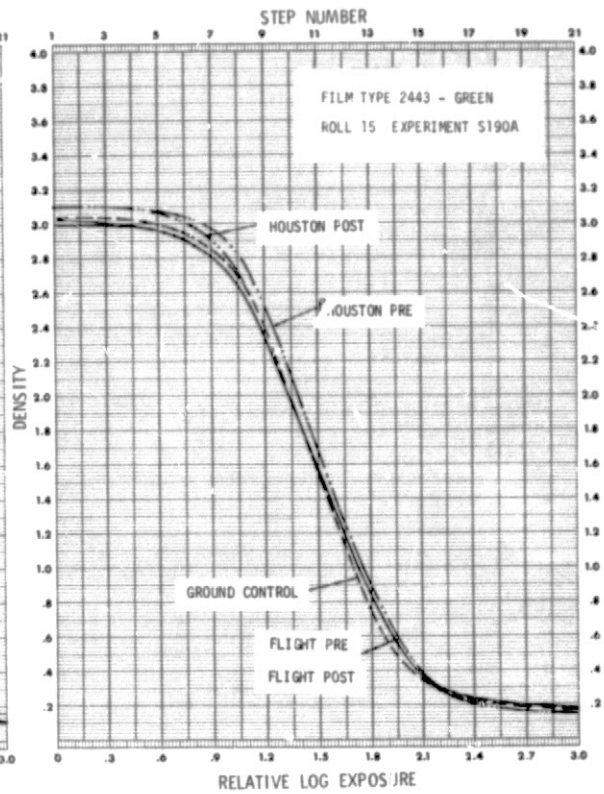


FIGURE D-109. FILM TYPE 2443, ROLL 15





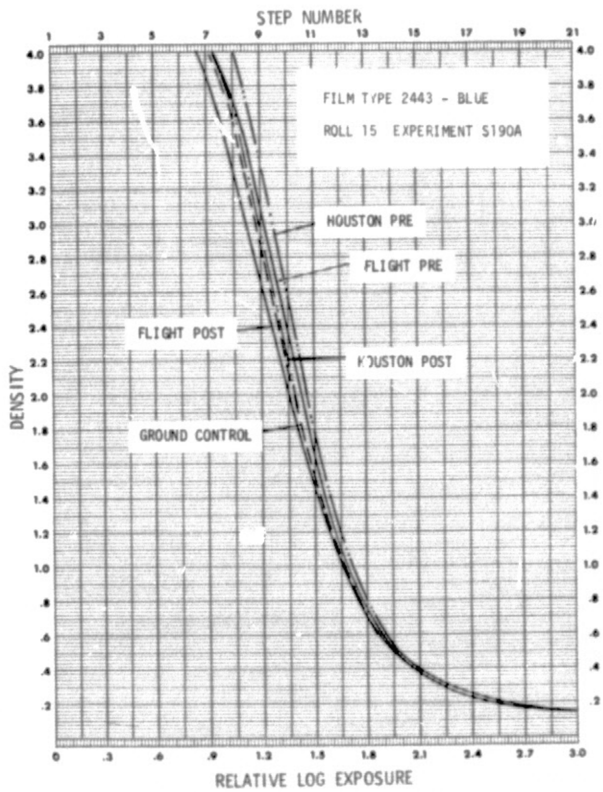
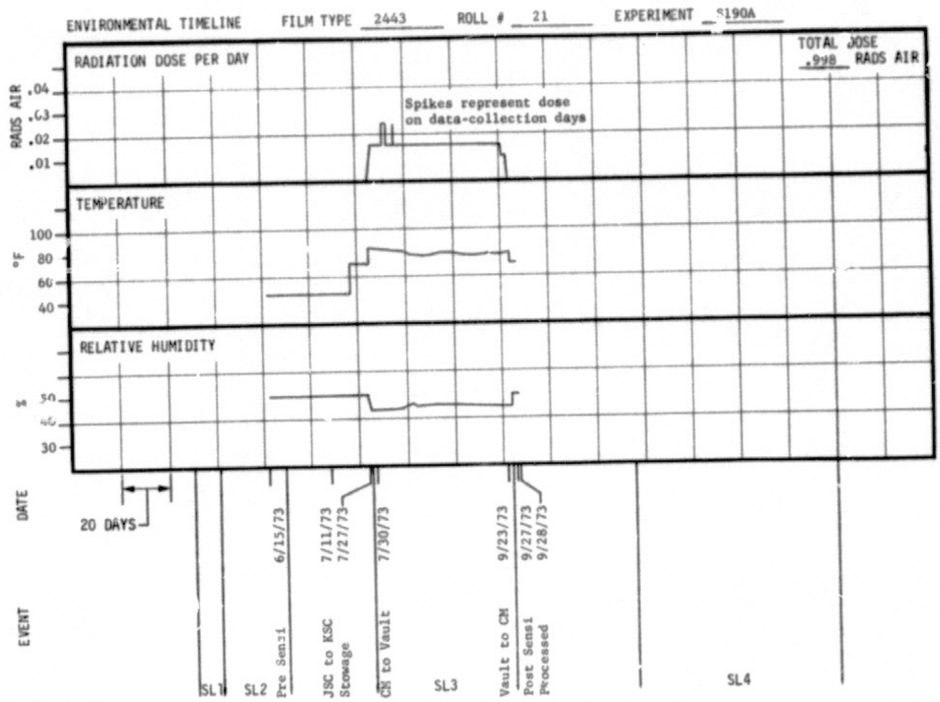


FIGURE D-109, FILM TYPE 2443, ROLL 15 (cont)



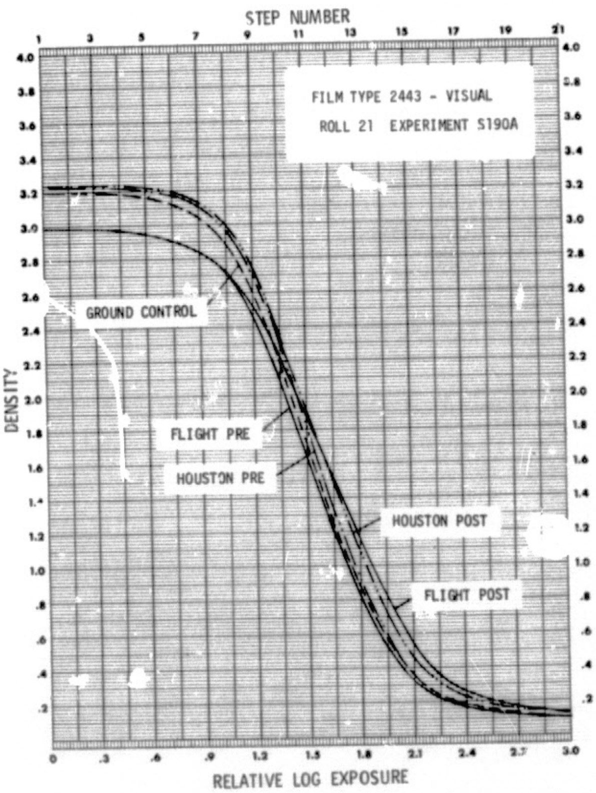
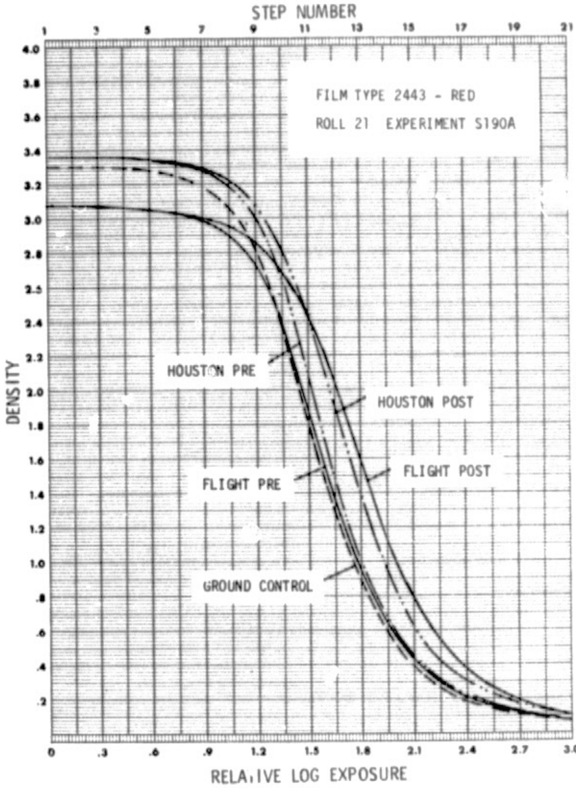
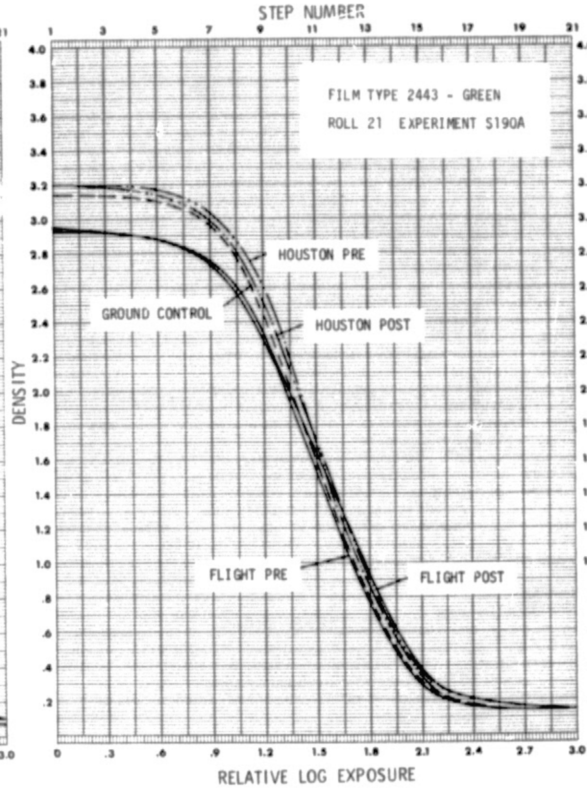


FIGURE D-110, FILM TYPE 2443, ROLL 21





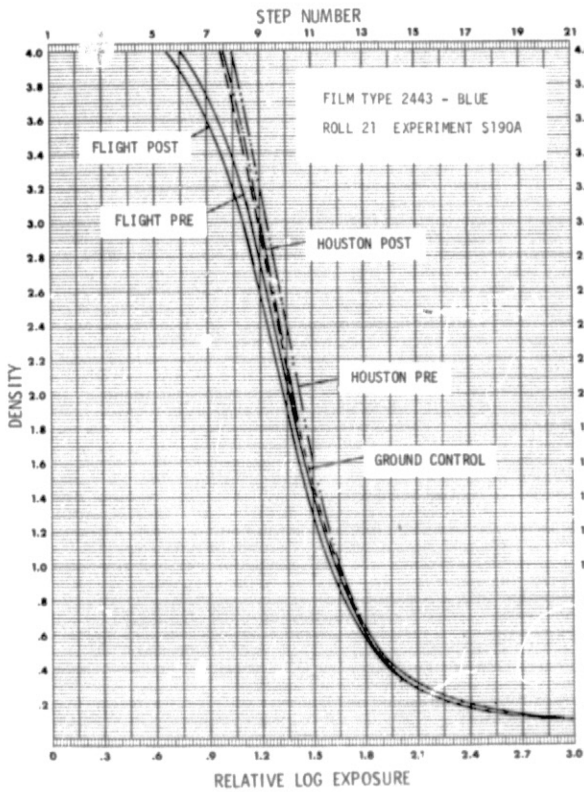
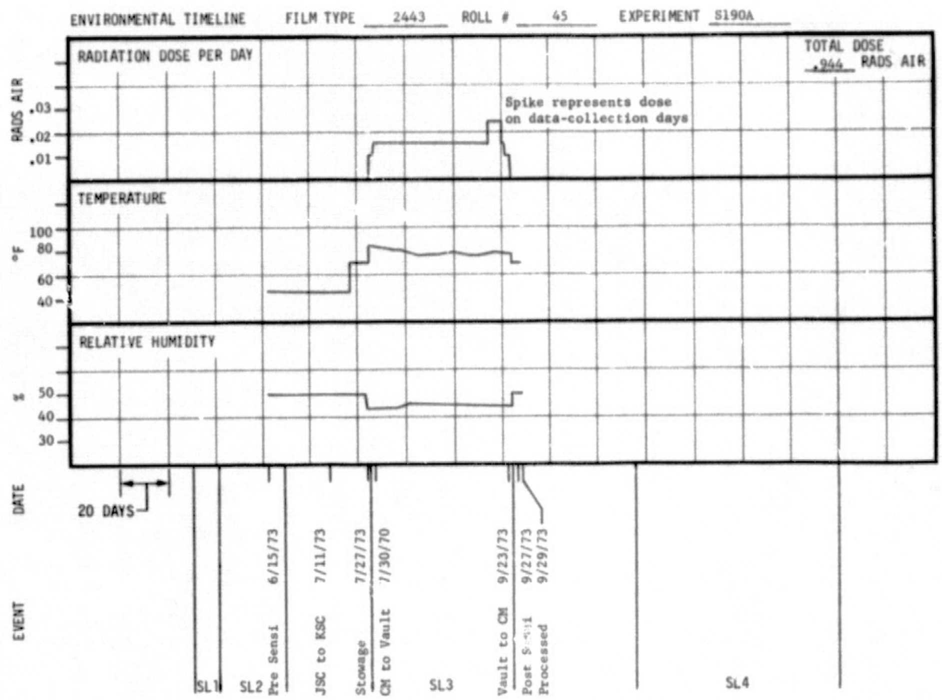


FIGURE D-110, FILM TYPE 2443, ROLL 21 (cont)



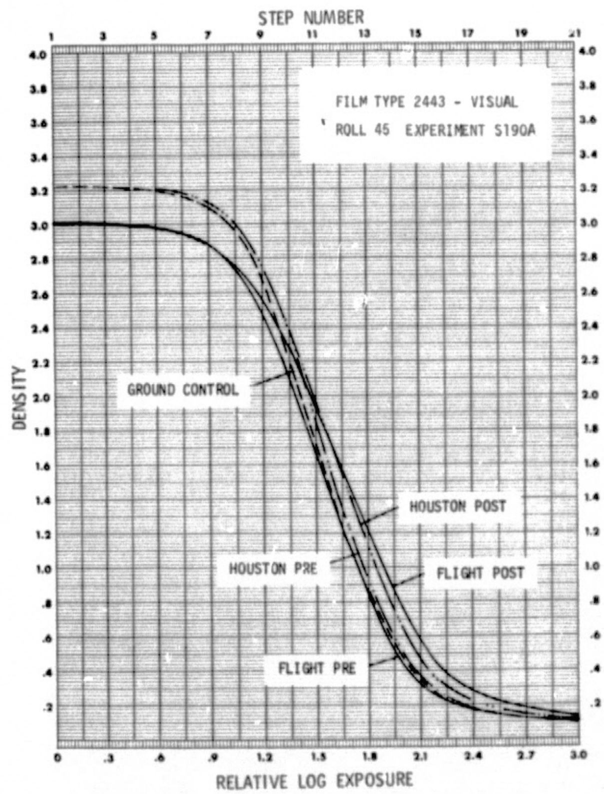


FIGURE D-III, FILM TYPE 2443, ROLL 45

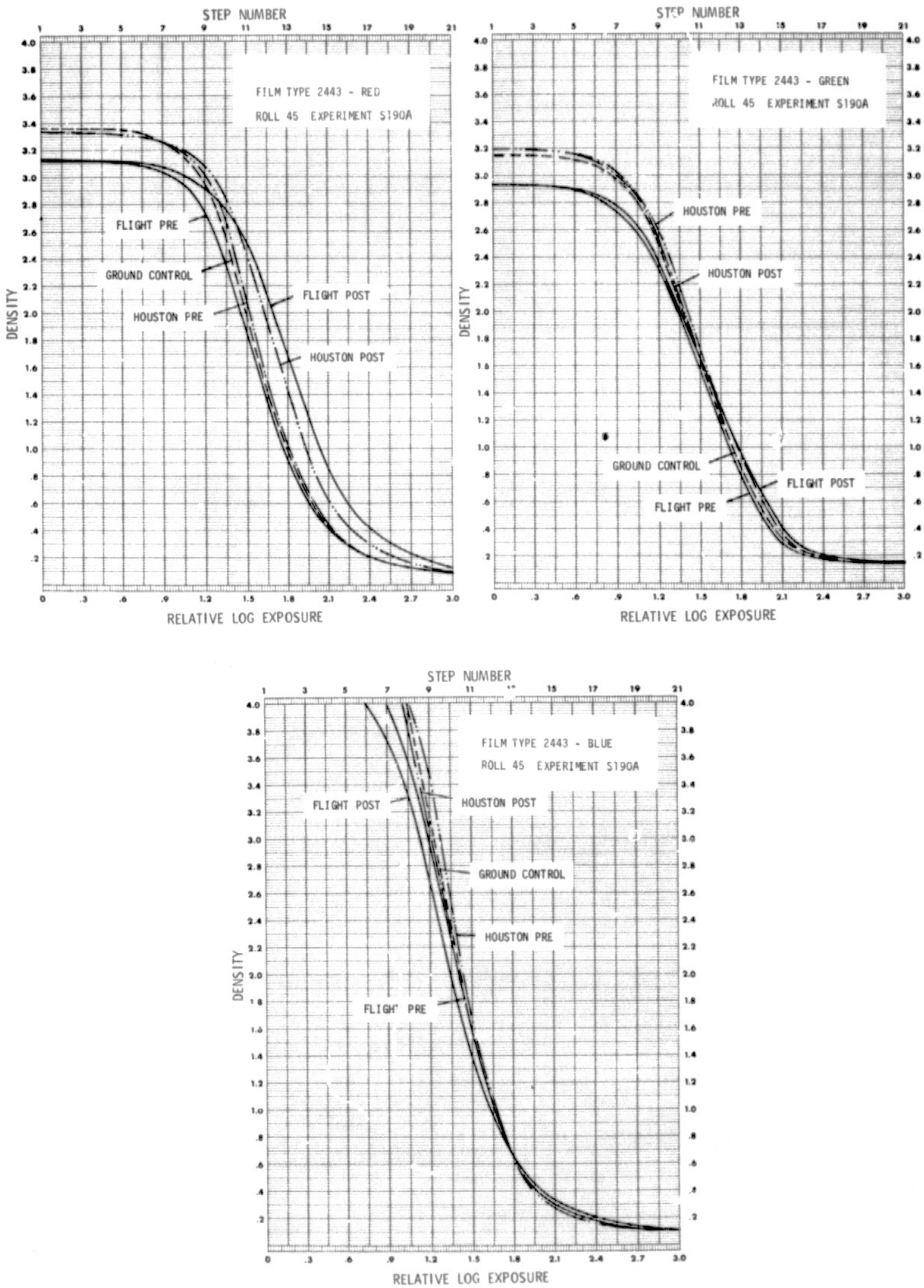
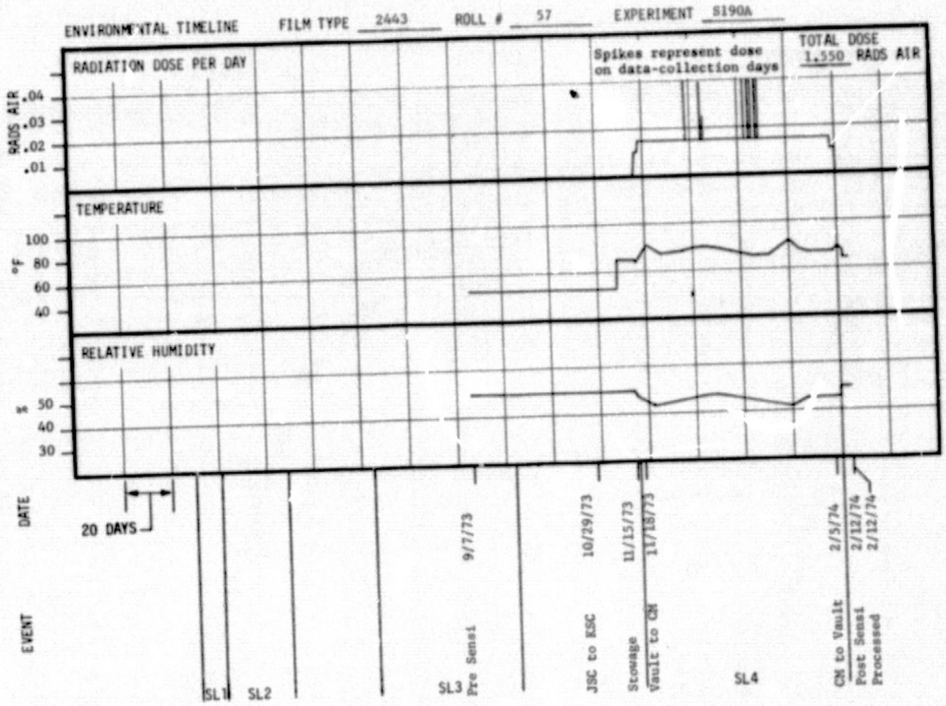


FIGURE D-III, FILM TYPE 2443, ROLL 45 (cont)



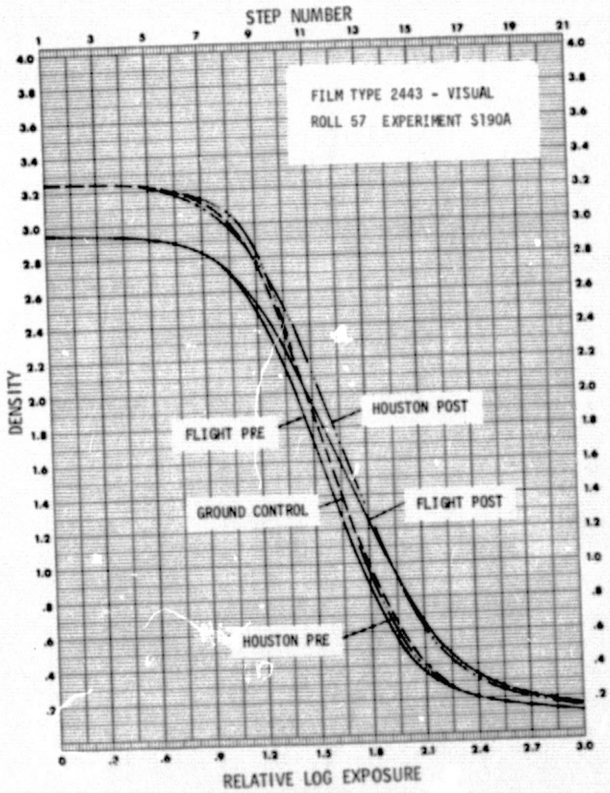
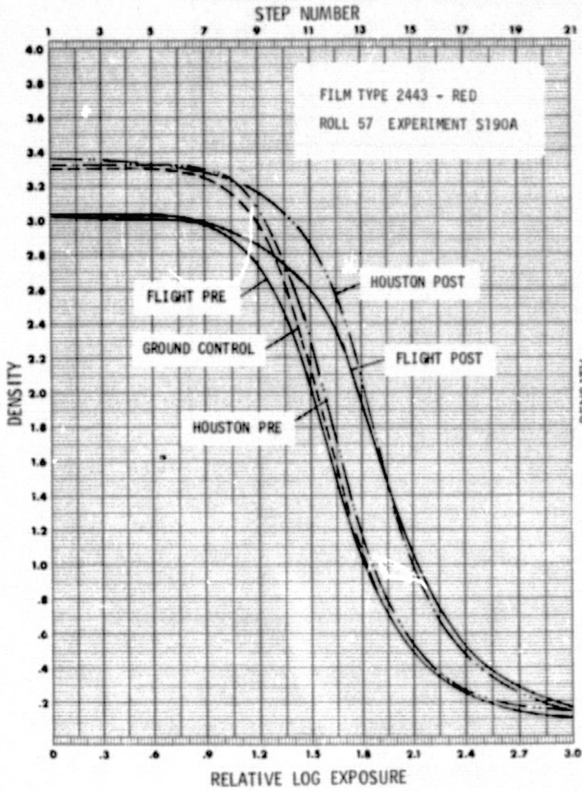
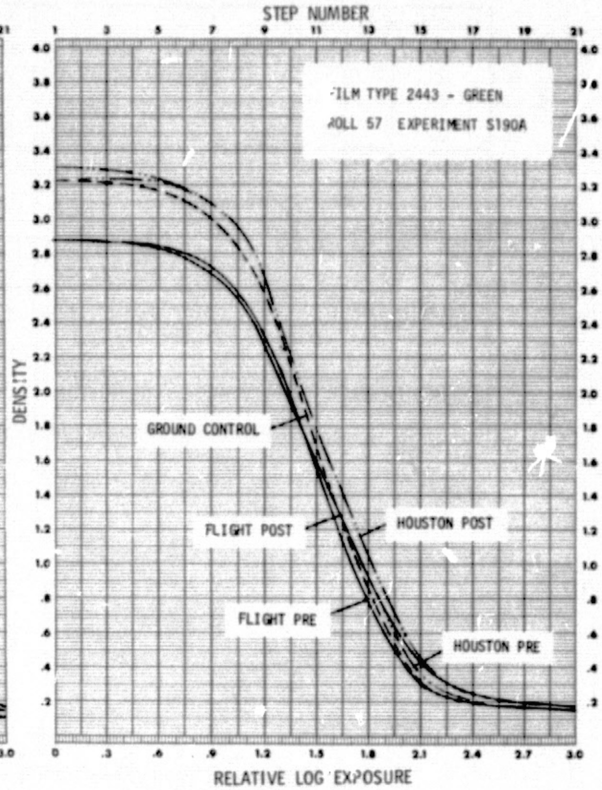


FIGURE D-112, FILM TYPE 2443, ROLL 57





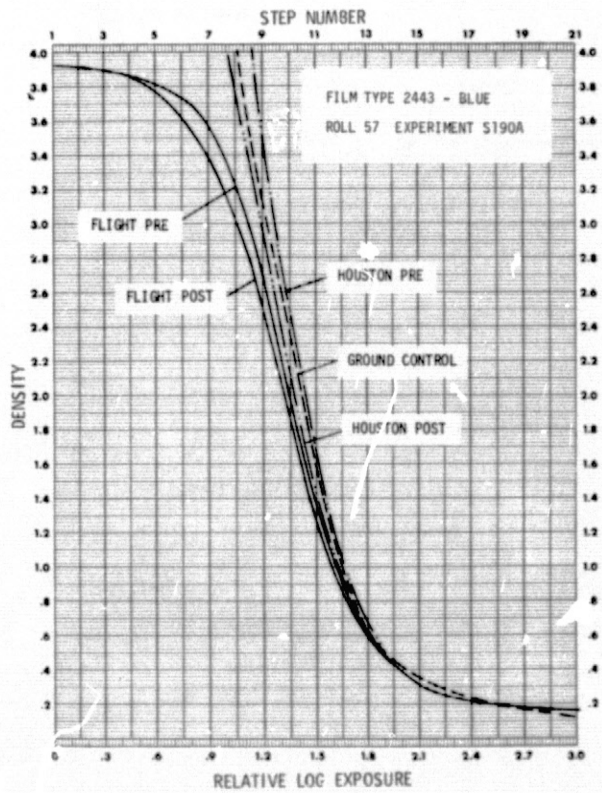
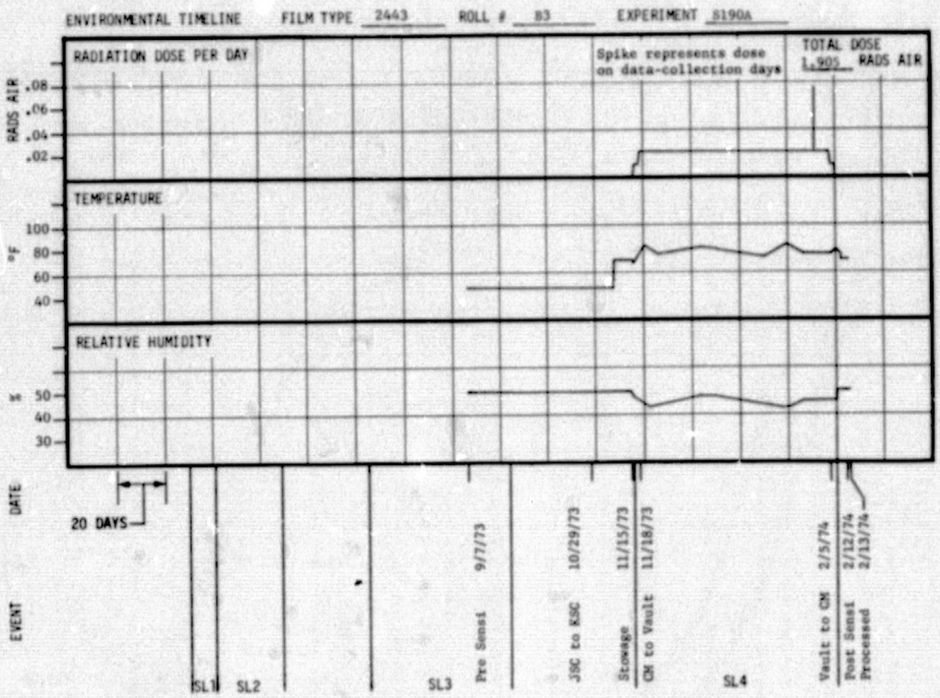


FIGURE D-112, FILM TYPE 2443, ROLL 57 (cont)



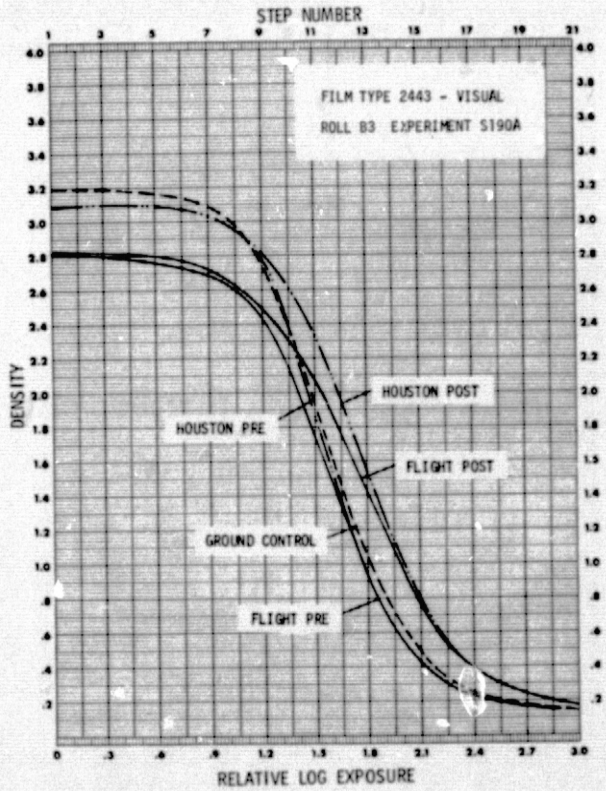


FIGURE D-113, FILM TYPE 2443, ROLL B3

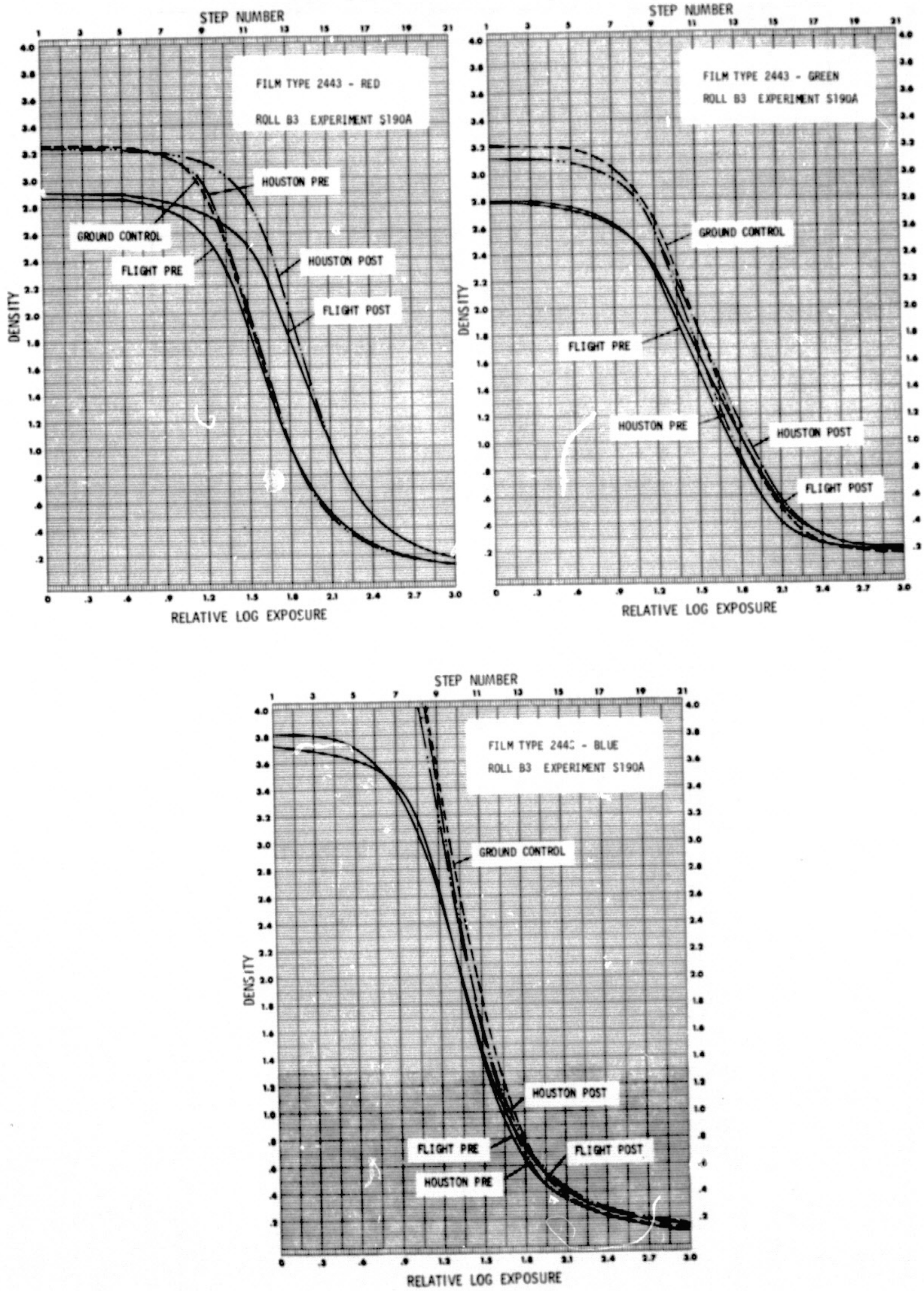
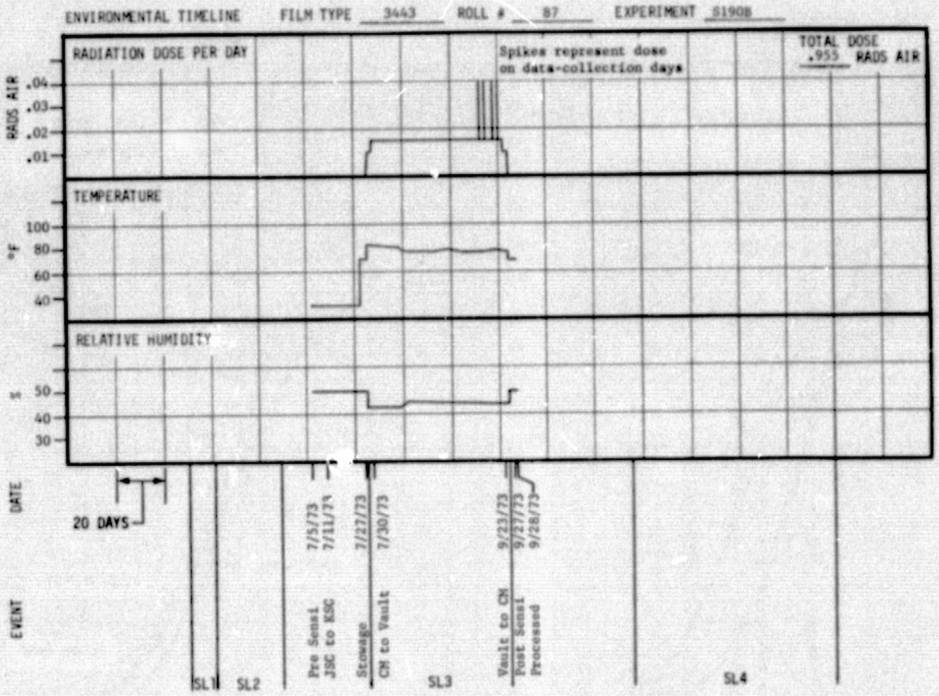


FIGURE D-113, FILM TYPE 2443, ROLL B3 (cont)



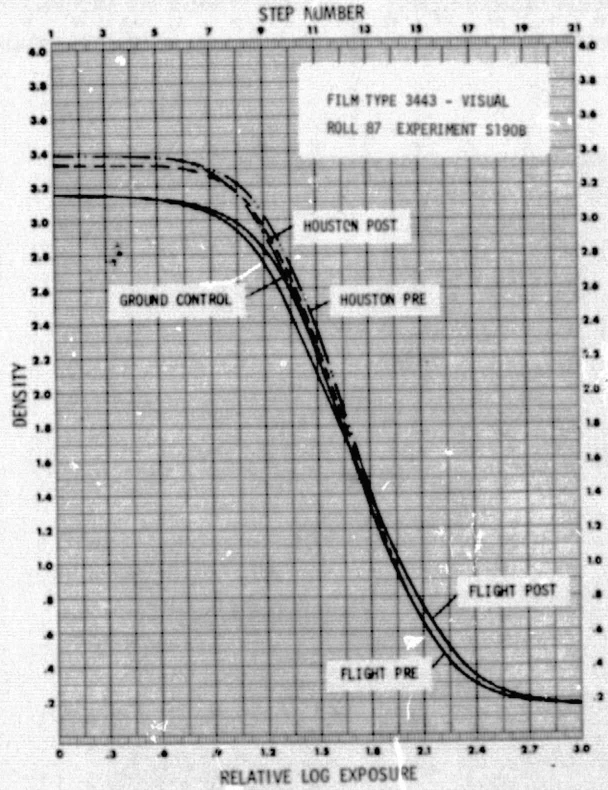


FIGURE D-114, FILM TYPE 3443, ROLL 87

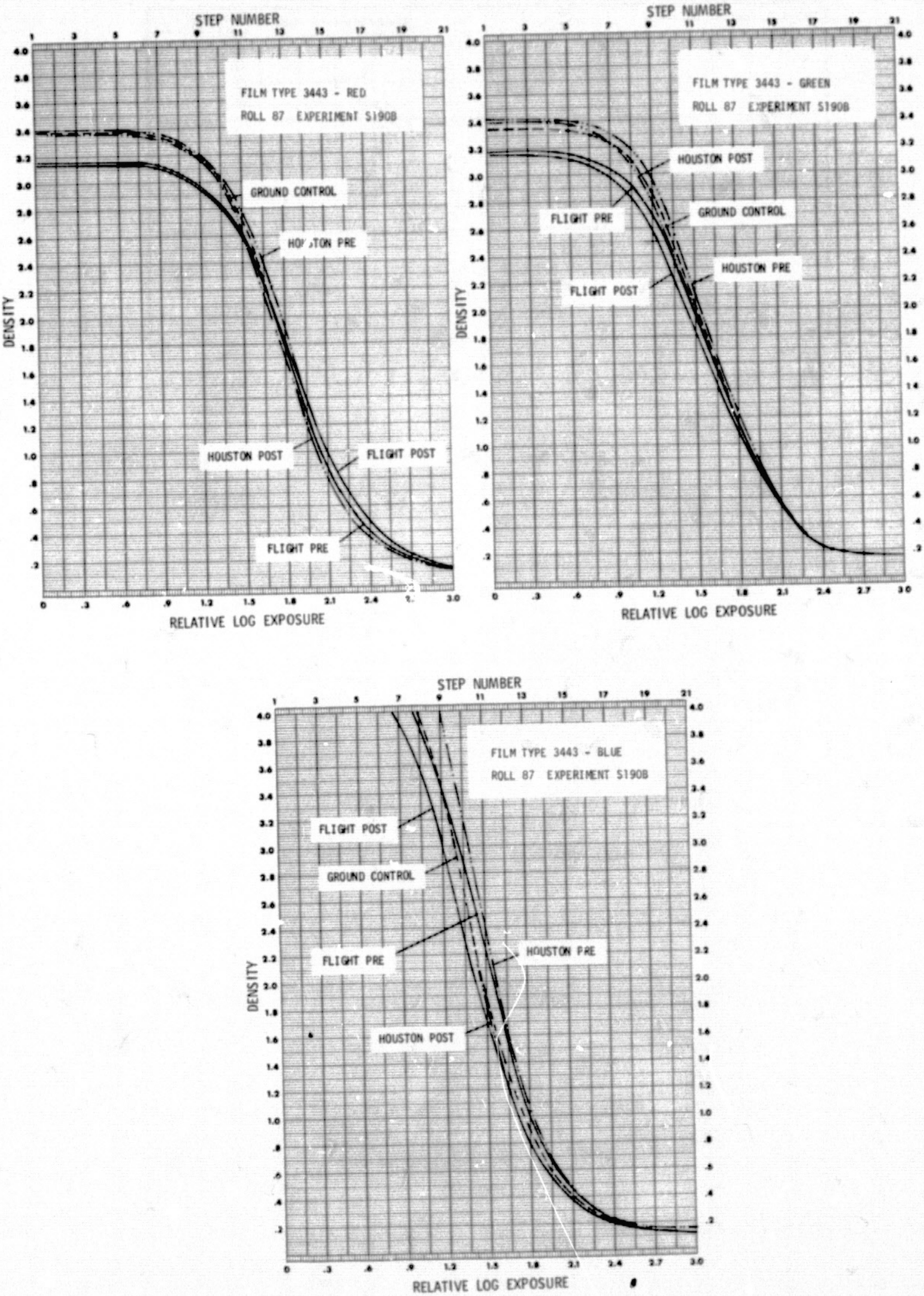
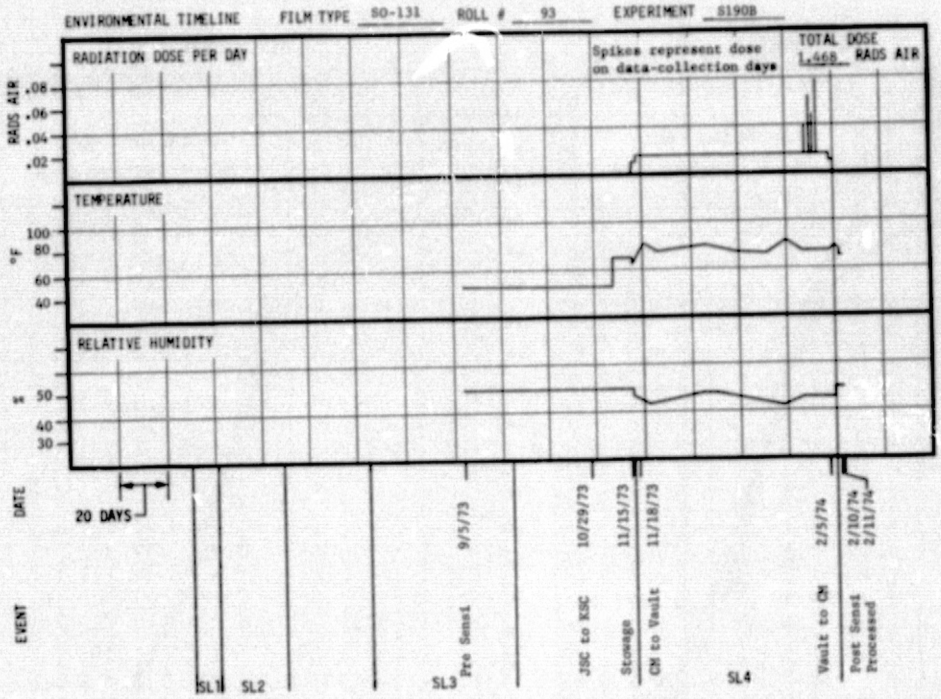


FIGURE D-114, FILM TYPE 3443, ROLL 87 (cont)



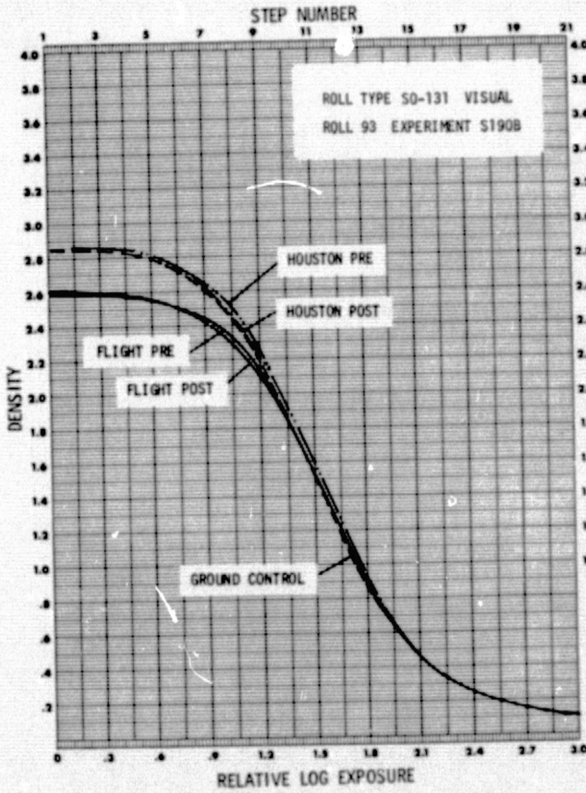


FIGURE D-115, FILM TYPE SO-131, ROLL 93

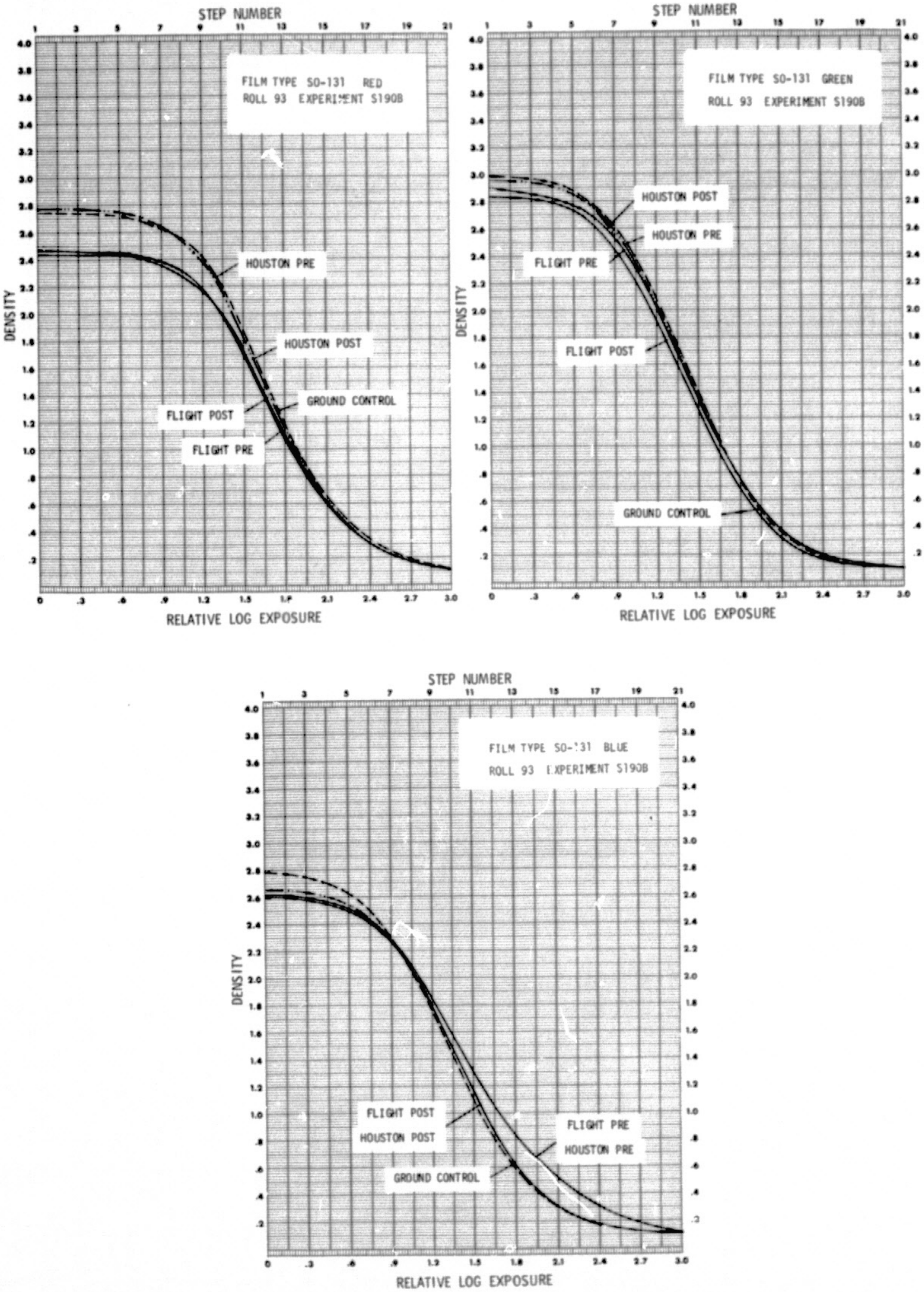


FIGURE D-115, FILM TYPE SO-131, ROLL 93 (cont)

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